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ON THE VENOUS NETWORK OF THE HUMAN HEART AND ITS ARTERIO-VENOUS ANASTOMOSES

BY

ALVARI AHO

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Contents

PREFACE 5
INTRODUCTION 7
SURVEY OF LITERATURE 9

Sinus Coronarius 10
Coronary Veins 12
Venae Cordis Minimae (Venae Thebesii) 20
Anastomoses 21

OWN INVESTIGATIONS 23

Material 23
Methods 26
Nomenclature Employed in this Work 32
Venae Coronariae 36
Sinus Coronarius 36
Individual Coronary Veins 42
Coronary Venous System as a Whole 60
Venae Cordis Minimae (Venae Thebesii) 69
Density Relations of Coronary Veins and Venae Cordis Minimae System 73
Anastomoses 77

SUMMARY 87
REFERENCES 88

Preface

It was the Director of the Wihuri Research Institute, PENTTI I. HALONEN, M.D., who in 1946 recommended to me research work on the venous systems of the heart, which actually proved to be a highly interesting field of research. I am greatly indebted to Doctor HALONEN, for the choice of this subject. I desire to take this opportunity to express to him, moreover, my gratitude for his kind support throughout the course of this investigation.

In the later stage of my work, some problems brought forth by the research led me to apply to Professor NIILO PESONEN, M.D., Director of the Department of Anatomy in the University of Helsinki, and I wish to express my appreciation to him for his benevolent and helpful guidance. I also acknowledge my indebtedness to Professor GÖRAN HJELMMAN, M.D. for very valuable advice in the preparation of this work.

My sincere thanks are due to Professor ARNO SAXÉN, M.D., Director of the Department of Pathological Anatomy in the University of Helsinki, for kindly placing material at my disposal and for thus contributing invaluable aid in the collection and selection of my material. For help in supplying material I am also indebted to Professor ARVO YLPPÖ, M.D., Director of the University Clinic for Children in Helsinki, and to VILJO RITAMA, M.D., Director of the Department of Pathology at the Kivelä, Hospital.

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For co-operation my thanks are also due to LIISA TÖTTERMAN, M.A., who has translated the work into English.

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Helsinki, September, 1949.

Introduction

In the study of the vessels of the heart far less attention has been devoted to the coronary veins than to the coronary arteries. Few investigations on the coronary veins based on more extensive materials have been carried out. Besides, they have chiefly been concerned with morphological aspects. The number of investigations has been too scarce, the material and the data reported not infrequently too inadequate to make it possible for the investigators to consider anthropological comparisons (e.g. for MOCHIZUKI to compare the Japanese and the European coronary systems of veins). Not until recent years has a more detailed study been carried out with a view to defining the anastomoses between the veins of the heart, as well as the anastomoses connecting the coronary veins and the coronary arteries. The author has, consequently, found some justification in considering in the present work both the morphology and the variability of the coronary veins and venae cordis minimae system. The author has also wished to devote some study to the various parts of the heart, such as the septum, the papillary muscles, and the venous system of the trabeculae, which have received very little attention earlier.

The literature does not yet present any details on the density and size relations of the coronary veins and venae cordis minimae system in the different parts of the same heart.

The present study may possibly also have some anthropological significance.

As a more extensive knowledge of the clinical, pathological, and patho-physiological aspects of the venous systems of the heart seems to be of increasing importance, a more detailed study of the arrangement of the network of coronary veins has been considered justified.

Survey of Literature

It is not intended to enter into details in surveying in this work the literature on the venous systems of the heart, as the matter will later be discussed with more thoroughness.

As early as in the 17th and 18th century the text-books and manuals of anatomy already present findings on the hearts own systems of veins (e.g. Bartholinus 1651, Vieussens 1705, Thebesius 1708, Verheyens 1712, Winslow 1732, LeCat, 1738).

In the work of Bartholinus there is a reference to two coronary veins termed: per cujus superficiem coronaria vena disseminatur and vena coronaria per cordis superficiem radicata diffusa. Vieussens and Verheyens know also two coronary veins. These veins always refer to the vena cordis magna and the vena cordis parva. Portal (1804) employs the term sinus coronaire of the entire left vein, and Krause, as late as 1879, terms it vena cordis magna s. sinus coronarius, although, prior to him, already, Winslow, Reid (1839), Marshall (1850), Cruveilhier (1852), and Gruber (1864) distinguish in this left coronary vein two parts: the sinus coronarius and the vena cordis magna.

By the 19th century, accordingly, three main divisions are distinguished in the venous circulation of the heart. These divisions are: 1) the sinus coronarius, 2) the left venous trunk, and 3) the right venous trunk. There is some knowledge, at that time, of a fourth division as well (the venae cordis minimae). LeCat, Marshall, and Siding (1896) are chiefly concerned with the sinus coronarius. The research directed to the coronary veins, however, although not considerable, resulted in some extension of the knowledge of that subject also (e.g. Jamain 1853, Béraud 1862, Gruber, Krause, Gray 1887, Gegenbaur 1896).

Sinus Coronarius

Theories on Boundaries of Sinus Coronarius

It is WINSLOW who introduces the term sinus coronarius, indicating the transverse segment of the vena cordis magna. CRUVEILHIER terms it sinus veineux, while REID's term sinus of the coronary vein refers to a still shorter segment, identical with the present conception of the sinus coronarius.

REID exactly determines the boundary between the sinus coronarius and the vena cordis magna. The terminal end of the sinus coronarius coincides with the termination of the striated muscle tissue in its wall. According to REID and MARSHALL, this transverse striation may terminate sharply, the demarcation line between the two tissues being clear-cut enough, whereas GRUBER holds that the striation actually overlaps the segment of the vena cordis magna. TANDLER (1913) points out that the striated muscle tissue need not extend to the valvula Vieussenii, as it may be entirely absent in the distal part of the sinus coronarius.

On macroscopical determination of the longitudinal measure of the sinus coronarius, this vein has been considered to extend from the valvula Vieussenii to the valvula Thebesii. In the absence of these valves, the determination of its terminal ends has been based on the difference in shape between the origin of the sinus coronarius and the terminal opening of the vena cordis magna and, further, on the aid offered by the left margin of the terminal opening of vena interventricularis dorsalis cordis (e.g. REID, MARSHALL, GRUBER, TANDLER, TESTUT 1928).

MECHANIK (1934) holds the view that, »Am genauesten wird diese Grenze durch die Lage der Valvula Vieussenii und nicht genügend bestimmt durch den linken Rand der gemeinsamen Muskulatur der Vorhöfe am Sinus coronarius angedeutet.» MOCHIZUKI (1933), again, makes the observation that the valvula Vieussenii may be lacking. As he also finds the above difference in shape not infrequently less distinct, in agreement with HIROTA (1928), he draws the boundary at the point of entrance of the vena obliqua atrii sinistri into the sinus coronarius.

Nomenclature

In the literature surveyed by the author the sinus coronarius is named by a variety of different terms. The term sinus coronarius has been accepted in the *B.N.A.* (Baseler nomina anatomica 1895), and in the *I.N.A.* (Jenaer nomina anatomica 1935). It has

been used by quite a number of investigators (e.g. GEGENBAUR, SPALTEHOLZ 1913, TANDLER, BRAUS 1924, MOCHIZUKI, HOCHREIN 1932, -41, MECHANIK, OKAJIMA 1934, PESONEN 1948). Some investigators, however, name the sinus coronarius by a vernacular term. The English equivalent chiefly employed is the sinus of the coronary vein (e.g. REID) or the coronary sinus (e.g. MARSHALL, CUNNINGHAM 1931, PATTEN 1942). The term employed by the French research workers is sinus coronaire (e.g. PIQUAND 1910, TESTUT) or sinus veineux (e.g. CRUVEILHIER, JAMAIN). It is emphasized by GRUBER that the function of the sinus coronarius is to act as the common outlet of all coronary veins. He, accordingly, recommends the use of the term sinus communis venarum cardiacarum, while KRAUSE seems to regard the sinus coronarius merely as a terminal bulge of the vena cordis magna, as he names it pars ampullaris venae coronariae magnae. IWANOW (1933), in addition, employs the term sinus venarum.

GRUBER describes the existence of so-called supplementary sinuses. By them he means the bulging enlargements occurring just before the openings of the veins which enter the sinus coronarius. Sinus venae coronariae magnae proprius is the term used by him for the enlargement of the vena cordis magna, sinus venae mediae proprius for the bulging part of the vena interventricularis dorsalis cordis, sinus venae mediae et venae parvae proprius for the bulge which the two corresponding veins have in common. The point at which MOCHIZUKI's terms differ, is the substitution of bulbus venae cordis mediae for sinus venae mediae proprius.

Localization and Opening

The investigators agree as to the localization of the sinus coronarius on the dorsal surface of the heart. It lies in the sulcus coronarius, the groove between the left atrium and ventricle, and always empties into the right atrium, if the heart is of normal structure.

According to the findings of BAUER (1896), OTT (1909), and BENEKE (1920), it may exceptionally open into the left atrium. The sinus coronarius may be atypical or entirely absent in such cases where the venae cavae present an anatomical structure deviating from the normal (e.g. LECAT, SIDING, GRUBER, MÖNCKEBERG 1924, ADACHI 1933, BIZZA 1942).

Coronary Veins

Nomenclature

A variety of names has been used of the different coronary veins, which tends to cause confusion. The nomenclature of the coronary veins is, therefore, reviewed here by way of introduction. The accompanying figure (Fig. 1) and table (Table I) will give a summary of the terms employed earlier.

Vena Cordis Magna

All investigators agree that the vena cordis magna almost without exception takes its origin from the ventral surface of the heart, arising from both sides of the sulcus interventricularis ventralis cordis. Its radicles, with their multiple subdivisions, are distributed over the regions of the right and left ventricle, the conus arteriosus, the left atrium and auricle. All branches of the right ventricle and some of the left one gather to form a venous trunk or a bundle of trunks ascending to the sulcus interventricularis ventralis cordis. This formation is termed by JAMAIN veines ascendentes, by KRAUSE ramus longitudinalis anterior, and by HOCHREIN vena interventricularis anterior.

In MOCHIZUKI's opinion, the vena cordis magna does not regularly take its origin from the apex of the heart, as is claimed by European research workers. According to him, its radicles extend over part of the ventral wall of the heart, but never continue round the apex to its dorsal wall. There is also a variable distribution of these topmost branches over the region of the left ventricle. Upon reaching the sulcus coronarius, the ascending branches unite to form a wide venous trunk running in this groove, at first to the left in the dorsal direction, and then to the right, and terminating by opening into the sinus coronarius. This transverse segment of the vena cordis magna also receives a number of branches from the regions of the left ventricle, left atrium and auricle.

The branches distributed to the left atrium and auricle are termed by JAMAIN veines descendentes, and by GRUBER venae posteriores atrii sinistri propriae et accessoriae. BÉRAUD and TESTUT describe, in addition, two venous cords emerging from the basal regions of the aorta and the arteria pulmonalis. TESTUT terms them la veine infundibulum pulmonaire.

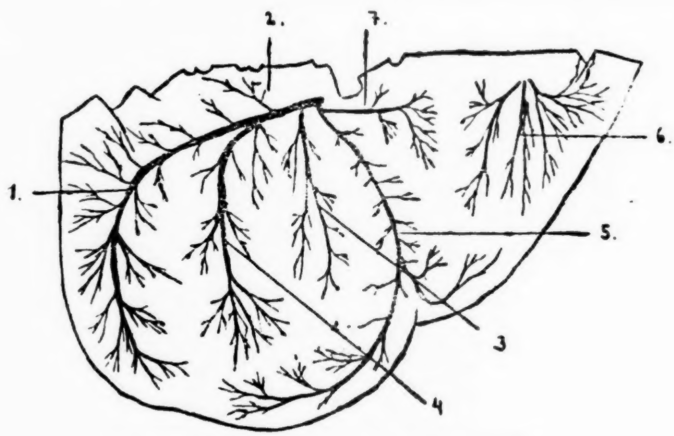


Fig. 1. The heart displayed on one plane.
In conformity with the I.N.A. the following nomenclature is used in the present work: 1. vena cordis magna, 2. vena obliqua atrii sinistri, 3**. and 4*. venae dorsales ventriculi sinistri[1], 5. vena interventricularis dorsalis cordis, 6. venae cordis ventrales, and 7. vena cordis parva.

Vena Obliqua Atrii Sinistri

The vena obliqua atrii sinistri is mostly a small vein, whose radicles arise from the wall of the outlet of the vena pulmonalis sinistra in the region of the left atrium. It may pass from there, i.e. from the lateral-dorsal wall of the left atrium (and almost always does so, when present) obliquely down between the pulmonary veins and the left auricle, opening, as a rule, into the orifice of the sinus coronarius, and receiving slender branches from its immediate neighbourhood. Gruber points out that it is fairly large in the embryo, but already in the 4th month of the foetal life it is, according to him, smaller than the vena cordis magna. Gruber and Mochizuki have made the observation that it may be entirely absent.

Venae Dorsales Ventriculi Sinistr

Table I shows that some investigators term the largest, or the two largest, of these veins by their own surnames. Mochizuki emphasizes that for these veins a name in the plural would be the most adequate one.

According to Gruber the venae dorsales ventriculi sinistri belong to the group of the venae posteriores. He includes to

[1] In Table I the corresponding veins are marked with stars as follows: 3** and 4*.

Table I: Nomenclature of the Coronary

1	2	3** and 4*
V. coronaria magna s. sin.	V. obliqua auricularis s. V. posterior atrii sin.	Veine du bord gauche du coeur* V. posterior ventriculi sin.** V. marginalis ventriculari sin.*
Grande veine coronaire	Veines descendentes	Veines ascendentes
V. cordis magna	V. obliqua atrii sin.	V. posterior ventriculi sin.
V. coronaria cordis magna	—»—	Ramus posterior ventriculi sin.
Great cardiac vein	An oblique vein	Posterior cardiac vein
V. cordis magna	V. obliqua atrii sin.	V. posterior ventriculi sin.
Veine coronaire gauche s. Grande coronaire des classiques	Veine oblique de l'oreillette gauche	Veine marginale gauche* Veine ventriculaire gauche postérieure**
V. magna cordis	V. obliqua atrii sin.	V. marginalis sin.*
		V. ventriculi sin.**
V. cordis magna	—»—	Vv. posteriores ventriculi sin.
V. magna cordis	—»—	V. marginalis sin.*
Grande veine coronaire	Veine de Marshall s. Veine oblique de l'oreillette gauche	V. ventriculi sin.** Veine postérieure du ventricule gauche*
V. cordis magna	V. obliqua atrii sin.	V. posterior ventriculi sin.
Great cardiac vein	Oblique vein of the left atrium	Inferior cardiac vein of the left ventricle
V. cordis magna	V. obliqua atrii sin.	Vv. posteriores ventriculi sin.
—»—	—»—	V. ventriculi sinistri posterior**
		V. marginalis ventriculi sin.*
—»—	—»—	V. posterior ventriculi sin.
V. cordis magna	V. obliqua atrii sin.	Vv. dorsales ventriculi sin.

Coronary Veins Used by Different Author's

5	6	7	Author
V. media	—	V.coronaria parva s.dx.	Gruber
Veine interventriculaire posterieure	Veines anterieures	Petites veines cardiaques	Jamain
V. cordis media	Vv. cordis anteriores	V. cordis parva	B.N.A.
V. coronaria cordis parva	V. coronaria cordis dextra anterior	V. coronaria cordis dextra posterior	Krause
Middle cardiac vein	Right cardiac vein	Small cardiac vein	Gray
V. cordis media	Vv. cordis anteriores	V. cordis parva	Henle
Veine interventriculaire postérieure	Veines ventriculaires antérieures droites	Veine coronaire droite	Piquand
V. cordis media	V. cordis parva	V. cordis dx.	Bardeleben
—»—	Vv. cordis anteriores	V. cordis parva	Spalteholz
V. interventricularis porterior	Vv. cordis parvae	V. coronaria dx.	Tandler
Veine interventriculaire postérieure	Vv. cordis minores	Petite veine coronaire	Testut
V. cordis media	—	V. cordis parva	Braus
Middle cardiac vein	Anterior cardiac vein	Small cardiac vein	Cunningham
V. cordis media	Vv. anteriores	V. cordis parva	Mochizuki
V. interventricularis posterior	Vv. parvae cordis	V. coronaria dx.	Hochrein
—»—	Vv. anteriores cordis	—»—	Mechanik
V. interventricularis dorsalis cordis	Vv. cordis ventrales	V. cordis parva	I.N.A.

them all those coronary veins which run to the sulcus coronarius from the regions of the left atrium and ventricle. He calls attention to two prominent branches, which also frequently spring from the left ventricle (the venae posteriores ventriculi propriae), as well as to a number of smaller branches (the venae posteriores ventriculi accessoriae), all of these veins lying between the vena interventricularis dorsalis cordis and the vena cordis magna.

The venae dorsales ventriculi sinistri may show marked variations in size and morphology. All large venae dorsales ventriculi sinistri may even be absent (MOCHIZUKI). These veins may open variably into the sinus coronarius, the vena cordis magna, or the vena interventricularis dorsalis cordis (e.g. GRUBER, MOCHIZUKI).

Vena Interventricularis Dorsalis Cordis

The vena interventricularis dorsalis cordis has been regarded as a single-stemmed coronary vein. MOCHIZUKI finds it capable of forming islands. Not infrequently, it arises from the dorsal and ventral surfaces of the apex. Its essential stem is formed, as a rule, in the distal part of the sulcus interventricularis dorsalis cordis, along which it runs, curving to the right towards the terminal opening of the sinus coronarius and emptying into it. It is noted by GRUBER, PIQUAND, and MECHANIK that it may also open directly into the right atrium. MOCHIZUKI has not observed this. He particularly emphasizes the significance of this vein as the drainer of the cardiac apex.

Vena Cordis Parva and Venae Cordis Ventrales

The vena cordis parva and the venae cordis ventrales are some of the most confusingly described coronary veins in the literature, which is probably due to the fact that variations occur most frequently in this region. It is, therefore, stressed by MOCHIZUKI that consistency should be observed in dealing with these vessels and their nomenclature. In his opinion the systems of the vena cordis parva and the venae cordis ventrales are entirely independent venous systems. If the whole ventral surface of the right ventricle is drained exclusively by the vena cordis parva, which empties into the sinus coronarius, and not one coronary vein opening directly into the right atrium is present (the venae cordis ventrales), the conclusion must be drawn that, in this case, the coronary venous system does not include the venae cordis ventrales, since, against the view of PIQUAND, they are to be

considered independent veins and not branches of the vena cordis parva. The two systems may be present simultaneously, one being prominent and the other poorly developed (e.g. PIQUAND, MOCHIZUKI, MECHANIK).

Vena Cordis Parva

The size of the vena cordis parva may vary considerably, ranging between a principal vein and quite a rudimentary branch of the vena interventricularis dorsalis cordis. It may even be entirely absent.

It is pointed out by PIQUAND that quite a number of investigators ignore it or make only a brief mention, such as the small coronary vein or the right coronary vein. He describes the vena cordis parva, when full-grown, as equal in size to no less than the great vein of the left heart (the vena cordis magna) and as the drainer of very nearly the whole ventral surface of the right ventricle.

The vena cordis parva may open into the sinus coronarius separately or jointly with the vena interventricularis dorsalis cordis. This common outlet is termed by TANDLER truncus venae interventricularis dorsalis cordis et venae cordis parvae. The vena cordis parva alone may also open directly into the right atrium, close to the orifice of the sinus coronarius, though it seldom does so (e.g. GRUBER, PIQUAND, MECHANIK). According to MOCHIZUKI, the vena cordis parva may have not less than two different outlets (Fig. 2), one opening into the sinus coronarius, the other into the right atrium, at the base of the right auricle.

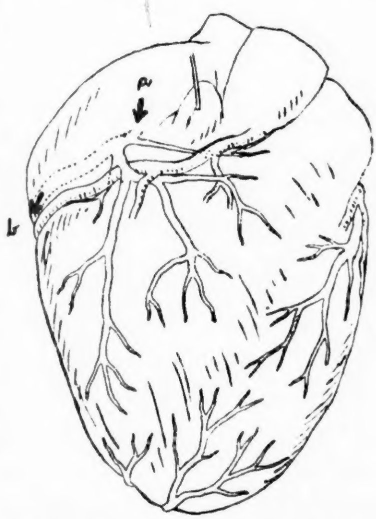


Fig. 2. The opening by two outlets of the vena cordis parva (MOCHIZUKI), an opening close to the right auricle (a), the main trunk of the vena cordis parva, lying in the sulcus coronarius (b), and opening into the sinus coronarius.

PIQUAND and MOCHIZUKI find that the vena cordis parva is often of prominent size, while it is found by GRUBER to be not

infrequently absent. PIQUAND and MECHANIK advance the view that the system of coronary veins in the right heart may show some development, its trend being that the system of the venae cordis ventrales show an increase and the system of the vena cordis parva a loss in size.

Venae Cordis Ventrales

The venae cordis ventrales consist of one or multiple veins, which may empty by one or more openings directly into the right atrium.

The individual veins of the venae cordis ventrales have been termed under a variety of titles, as follows: 1) vena cordis ventralis dextra, 2) vena cordis ventralis sinistra (MECHANIK), 3) vena Galeni, vena marginalis dextra (e.g. MOCHIZUKI, MECHANIK), 4) vena Gruveilhier (e.g. GRUBER, TESTUT, MOCHIZUKI) 5) vena Zuckerkandl (e.g. TESTUT, MOCHIZUKI). The following terms have been used, in addition: 1) venae cordis anteriores dextrae, 2) venae ventriculi dextrae posteriores (MECHANIK), and 3) veines ventriculaires anterieures droites (PIQUAND). It is, however, occasionally difficult, in comparing the terms used by the various investigators, to determine, which vein each of the term indicates.

DAVIDA (1923) has observed veins which are distributed over the ventral surface of the right ventricle, but open into the base of the vena cava cranialis. They are described by him under the title of venae extraordinariae I, II, and III. The same observation has been made by MOCHIZUKI, who does not, however, name these veins by special terms. He seems to classify them among the venae cordis ventrales.

Divisions of Coronary Veins

The coronary venous system has been divided into parts in varying ways. The commonest has been the grouping into two divisions, but the dividing principles have varied, either according to the region over which the coronary veins are distributed or according to the morphology of the venous trunks. The earliest division distinguishes two main venous trunks, a left and a right, which, according to the present nomenclature, are identical with the vena cordis magna and the vena cordis parva (e.g. VIEUSSENS, VERHEYENS) or with the coronary veins opening into the sinus coronarius and the coronary veins opening into the right

atrium (e.g. TANDLER, HOCHREIN). A division of the coronary veins into large and slender ones also exists. According to it, the venae cordis minores would be identical with certain coronary veins of small calibre (e.g. JAMAIN, GRAY, TESTUT, CUNNINGHAM). A distinction has, further, been made between superficial and deep coronary veins (e.g. MECHANIK, GREGG 1946). TANDLER introduces the following three divisions: 1) the vena cordis magna, 2) the vena obliqua atrii sinistri, and 3) the truncus communis venae interventricularis dorsalis cordis et venae cordis parvae. The three-part division presented by HOCHREIN is as follows: 1) the vena cordis magna, 2) the vena interventricularis dorsalis cordis, and 3) the vena cordis parva.

Earlier Investigations

Few investigations on the coronary veins are based on more extensive materials have been carried out. The accompanying table (Table II) presents the earlier investigations encountered in the literature and shows also the number of the hearts studied.

Table II. Investigations on Coronary Veins

Investigator	Material	Nationality	Year
GRUBER	130 hearts	Russian	1864
MOCHIZUKI	160 »	Japanese	1933
MECHANIK	160 »	Russian	1934

It is emphasized by MOCHIZUKI that the investigations carried out before his own cannot serve as material for comparative study. He writes: »*Selbst bei den Europäern ist die Untersuchung der Herzvenen heute noch so mangelhaft, dass man die Befunde an den Japanern nicht mit denen an den Europäern vergleichen kann.*» MOCHIZUKI's research material, however, includes only a few hearts from adult females, while the other investigators make no mention whatever of the sex ratio of their material. MECHANIK, again, directs his study to the system of the coronary veins as a whole, from the point of view of the development of these veins, without considering the details. His material, accordingly, does not afford any notable opportunity for comparisons. Nor does the literature surveyed include any work on the subject in which the material is classified into distinct age groups.

Venae Cordis Minimae

(Venae Thebesii)

Vieussens and Thebesius are the first to detect on the inner surface of the cardiac cavities minute apertures, which they consider to be terminal openings of small veins. Haller (1757), Sénac (1774), Theile (1841), Duvernois (1860), Gruveilhier, Luschka (1863), and Nussbaum (1912) regard them merely as blind recesses of the endocardium. Verheyens, Abernethy (1728), Lancisius (1728), Bochdalek (1868), Lannelonque (1868), Langer (1880), Gegenbaur, Pratt (1898), and Lewis (1904) see in them orifices of small veins, terming these veins either venae cordis minimae or venae Thebesii and their orifices, again foramina venae Thebesii or foramina venae cordis minimae. The terminal openings of these small veins in the right atrium are named by Testut foramina Lannelonque. The whole system of these veins is listed in the *I.N.A.* under the title of venae cordis minimae.

The anatomy of the venae cordis minimae has been studied, further, by Kretz (1928), Wearn (1928 and -33), Grant & Viko (1930), Laery & Wearn (1930), Spalteholz (1935), Unger (1937), Halonen & Tossavainen (1941), and Windt (1943). They have found the number of these veins appreciable and the size of their orifices up to 1 mm in diameter. They are more numerous in the atria than in the ventricles and most numerous in the region of the right atrium, from where the venous blood is drained by the venae cordis minimae into the cavity of the right atrium. These veins occur less abundantly in the region of the left atrium, most of the venous blood of this region being drained via the coronary veins into the sinus coronarius and from there into the right atrium. Also the right ventricle shows a greater number of the venae cordis minimae than the left. The venous blood of the right ventricle is drained partly by the system of the venae cordis minimae into the cavity of the right ventricle, whereas the drainage of the left ventricle occurs primarily via the coronary veins into the sinus coronarius, only a small amount of the venous blood being passed by the venae cordis minimae directly into the left ventricle. The system of the venae cordis minimae is distributed to all regions of the heart as a part of its own venous network.

In the ventricles these veins occur particularly abundantly in the apical region and in the septum, further, in the trabaculae and the papillary muscles, and also around the bases of the great cardiac vessels.

It seems appropriate to touch also briefly upon the role of the system of the venae cordis minimae. Numerous physiological experiments have actually been carried out with a view to making it clear. There is, however, no conclusive opinion yet concerning the role of the venae cordis minimae. The opinions seem, in fact, to be incompatible. It has been found by KRETZ, WEARN, GRANT & VIKO, UNGER, and HALONEN & TOSSAVAINEN that the terminal openings of the venae cordis minimae system are more numerous than has been supposed.

Physiological experiments carried out with a view to determining the significance of the venae cordis minimae in the blood circulation of the heart have shown that the venae cordis minimae system plays an important role in this circulation (e.g. PRATT, MORAWITZ & ZAHN 1912, MARKWALDER & STARLING 1914, CRAINICIANU 1922, KRETZ, IWANOW, WEARN, UNGER, HALONEN & AHO 1948). Another observation is that the variations in the differences in pressure between the two ventricles always exert a given influence upon the blood volume discharged by the venae cordis minimae system (e.g. STELLA 1931, JOHNSSON & WIGGERS 1937, KATZ, JOHIM, et al. 1938, MOE & VISSCHER 1939, BELLET 1946, GREGG & SHIPLEY 1947).

Anastomoses

Anastomoses between Coronary Veins

GRUBER, TESTUT, SPALTEHOLZ, HOCHREIN, MOCHIZUKI, GREGG, SHIPLEY, et al. (1943), GREGG & SHIPLEY, and COODALE, LUBIN, et al. (1948), find that the great coronary veins may anastomose with one another. It is MECHANIK who calls special attention to the anastomoses between the coronary veins. He divides them into the following two types. *Type 1:* »Sie vereinigen die einzelnen Venen des linken Teils des Herzvenennetzes, welcher nach dem Typ einer Kollektor gebaut ist. Das sind sozusagen Anastomosen in Innern des Systems. Besonders häufig begegnen wir hier Anastomosen des endständigen Types, welche sich an der Herzspitze anordnen.» *Type 2:* »Die zweite Anastomosengruppe ver-

bindet die Venen des rechten Netzteils — des intramuralen Teils — ausserdem selbständig in den rechten Vorhof münden, sosondert das Vorhandensein derartiger Anastomosen zwischen den System am Herzen die Zonen des doppelten Abfluss ab. Zu diesen Zonen gehören vornehmlich die Wände der rechten Herzkammer: das Venenblut derselben kann augenscheinlich auch direkt intramural in dem rechten Vorhof mittels Anastomosen zwischen den System in den Hauptkollektor, in den Sinus coronarius münden.» MECHANIK holds that the anastomoses of Type 2 are not terminal ones, as are those of Type 1.

Extra-Cardial Anastomoses of Coronary Veins

It is noted by BÉRAUD, ARNOLD (1847), LANGER, KRAUSE, and TESTUT that around the orifices of the aorta and the arteria pulmonalis there are small veins, which may anastomose with one another extracardially. They are generally looked upon as some of the vasa vasorum of the aorta and the arteria pulmonalis. GREGG says of the extracardial anastomoses, »There are numerous anastomotic channels connecting the coronary veins of auricles and ventricles with extracardial veins draining into the superior and inferior venae cavae.»

Arterio-Venous Anastomoses

CRAINICIANU, IWANOW, KRETZ, SPALTEHOLZ, WEARN, and WINDT call attention to so-called arterio-venous anastomoses connecting the coronary arteries and veins. The existence and calibre of these anastomoses are established conclusively by PRINZMETAL, SIMKIN, et al. (1947).

Anastomoses of Venae Cordis Minimae

The fact that the venae cordis minimae anastomose with one another has long been known (e.g. BOCHDALEK, LANNELONQUE, LANGER, PRATT, WEARN, UNGER, HALONEN & TOSSAVAINEN). WEARN introduces the terms »arterio-luminal vessels», »arterio-sinusoidal vessels» and »Thebesian vessels», which have actually become established in the literature, and they indicate the immediate connections of the venae cordis minimae to the coronary arteries, the sinusoids, and the coronary veins. PRINZMETAL, SINKIN, et al. have determined the calibres of these anastomoses.

Own Investigations

Material

The material employed in the present investigation comprises 200 human hearts obtained from autopsy material. The age varied within the range of a few minutes after birth and 93 years. Morphological examinations of the coronary venous systems were carried out in 160 hearts, 60 of these falling into the group of post-partum subjects (= p.p.) and 100 into the group of adults (= a.) By means of experimental glass bead injections 25 hearts were examined for the presence of anastomoses, the age of the cases ranging from one hour to 63 years. Histological examinations were performed on 15 hearts, whose age varied from 21 to 62 years.

The accompanying tables (Tables III, IV, and V) show the sources of the material and, further, the distribution of this material according to age, sex, and cause of death.

Table III: Sources of Material

Institution	Total	P P		A	
		♀	♂	♀	♂
Department of Pathological Anatomy of the University of Helsinki	135	8	9	57	61
Departement of Anatomy of the University of Helsinki	20	7	6	—	7
Children's Clinic	42	20	22	—	—
Kivelä Hospital	3	—	—	1	2
Total material	200	35	37	58	70

Table IV: Distribution of Material according to Age and Sex

Age	No of Cases ♀	No of Cases ♂	Total
Morphological Examinations			
P.P.	30	30	60
18 yrs — 30 yrs	10	11	21
31 yrs — 40 yrs	9	10	19
41 yrs — 50 yrs	10	17	27
51 yrs — 60 yrs	4	9	13
61 yrs — 70 yrs	7	8	15
71 yrs — 80 yrs	2	2	4
Over 80 yrs	1	—	1
Total	73	87	160
Experiments with Glass bead Injections			
P.P.	5	7	12
1 yr — 5 yrs	0	1	1
21 yrs — 30 yrs	2	2	4
31 yrs — 40 yrs	1	2	3
41 yrs — 50 yrs	1	—	1
51 yrs — 60 yrs	1	1	2
61 yrs — 70 yrs	1	1	2
Total	11	14	25
Histological Examinations			
21 yrs — 30 yrs	1	1	2
31 yrs — 40 yrs	4	3	7
41 yrs — 50 yrs	3	1	4
51 yrs — 60 yrs	—	1	1
61 yrs — 70 yrs	1	—	1
Total	9	6	15
Total material	93	107	200

In the classification of the material into age groups it was not necessary to apply RÖSSLE & ROULET's (1932) grouping: post partum — 6 mths, 7 — 12 mths, 1 yr, 2 yrs, 3 yrs, ... 20 yrs, 21—25 yrs, 26—30 yrs etc., as the distribution of the present material into the corresponding age groups would have been too disproportionate. In this investigation the author has found it expedient to follow MECHANIK's leading principles, according to which

Table V: Distribution of Material according to Cause of Death

Cause of Death	No of cases
Laesiones intra partum	4
Vitia primae conformationes	1
Diphteria	2
Gastroenteritis	33
Hepatitis	1
Poliomyelitis	1
Syphilis	4
Tuberculosis	11
Leucaemia	6
Lymphogranulomatosis maligna	4
Alii morbi sangvinis	3
Vitium cordis congenita	2
Diabetes mellitus	2
Pneumonia	36
Cirrhosis hepatis	4
Ulcus ventriculi s. duodeni	6
Peritonitis	7
Nephropathia	11
Septicaemia post abortum	2
Tumor malignum	32
Mors subita	2
Alii casus	26
Total material	200

there were only two age groups: the »embryonic» and the »post-embryonic». According to this division the present material showed the following two groups: 1) subjects succumbed immediately after birth (p. p.), and 2) subjects aged 18 or more (a). The former group had already terminated the embryonic stage, the latter was presumed to show a heart structure which corresponds to the adult one. In this investigation the author also considered the divergences and resemblances of the two sexes and carried out comparisons. For this purpose the material was, in addition, divided on the basis of sex.

Methods

Technique The heart was removed for examination immediately after autopsy. Some of the hearts were removed together with the lung complex to make possible defining of the extracardial anastomoses, whereas the rest were separated from the lung complex. The separation was carried out as follows: 1) The aorta ascendens and the arteria pulmonalis were cut off about 1 cm proximally to the corresponding valves. 2) The heart was lifted up in such a way that the lung complex was practically suspended by it, and the venae pulmonales were excised not far from the pulmonary hila. 3) The next step was to make preparations to expose the vena cava cranialis, which was then cut off as far up as possible. The examinations were carried out within 6 to 48 hours after the moment of death.

The heart and its cavities were washed with physiological saline by means of a hypodermic syringe (e. g. Kurkowsky 1933), which was also made use of in clearing from blood the arteries and veins. The rigidity of death was eliminated by immersing the heart into ice-water for 2 to 5 hours, after which procedures the heart was ready to be examined.

The injection material employed was the dye composed by Spalteholz, containing chrome yellow and gelatin, and also the mixture of India-ink and gelatin used by Unger. Before application the mixture was warmed up to 38° C. The heart was injected, while submerged into the physiological saline of 38° C. To reduce the viscosity of the injection dye, the heart was again immersed into ice-water, where it had to remain for several hours.

The coronary veins were injected via the sinus coronarius by aid of a hypodermic syringe and a cannula, the venae cordis ventrales being, when necessary, injected through their terminal openings in the right atrium. The vena cordis parva always filled up, when injected from the sinus coronarius. Via the vena cava caudalis the cannula was introduced into the right atrium and from there into the sinus coronarius. To bring into view the extra-cardial anastomoses or the venae cordis minimae of the atria, the injection was made via the sinus coronarius, but to define the venous network of the right heart (the venae cordis ventrales), the cannula had to be introduced into the vena interventricularis

dorsalis cordis, the right and the left venous network of the heart becoming thus filled simultaneously on injection. To keep the cannula in place, it was fastened firmly with silk by aid of a skin-needle. After this the injecting could commence. Immediately after the removal of the cannula the sinus coronarius was ligated with the silk by tightening up its movable loop. Before filling the syringe with injection material, it was warmed up to 40° C. During the injection the syringe also was immersed in heated saline in order to avoid clotting of the dye. The injecting was continued until the coronary veins of the right side were filled, too. In the event of obstruction, which meant the risk of rupture of the intermuscular network of veins, the injecting was discontinued and was completed through the terminal openings of the venae cordis ventrales. The last step was to immerse the heart into icy water. After this process the hearts were stored in 10 % formalin solution.

For examination the hearts were opened by Rieseman's (1943) serial dissection method: *Incision 1.* The ventral surface of the arteria pulmonalis was split with scissors as far as the ventral border of the septum interventriculorum. Then the ventral wall of the right ventricle was incised along the ventral border of the septum interventriculorum as far as its end. The right ventricle was thus exposed, while the septum interventriculorum remained intact. *Incision 2.* The aorta and the arteria pulmonalis were split by a single incision carried between the orifices of the coronary veins as far as the base of the septum interventriculorum along its ventral side. *Incision 3.* The septum interventriculorum was removed intact from its point of attachment in the external wall of the ventricles. *Incision 4.* The valves were removed by an incision proximally to their basal rings, and also the chordae tendineae. *Incision 5.* The aorta was incised once more at that part of its base which coincides with the base of the septum interventriculorum, the left ventricle being opened at the same time. The incision was carried along the line formed by the orifices of the venae pulmonales as far as the vena cava cranialis. In this manner the heart can be displayed on one plane for radiographic, photographic, or graphic study.

The following serial incisions were carried out for study of the septum interventriculorum: *Incision 1.* The right ventricle

was exposed via the vena cava caudalis by penetrating into the right atrium, whose ventral wall was partly opened by HAMPERL's (1941) autopsy technique. *Incision 2.* The left atrium was exposed, and through it the left ventricle was reached. The wall was again partly opened according to the above mentioned technique. *Incision 3.* The chordae tendineae were cut and the valves were removed by an incision proximally to their basal rings. *Incision 4.* The heart was incised by a transverse section along the basal rings of the atrioventricular and aortic valves. In this manner also the orifices of those veins which arise from the septum interventriculorum as tributaries of the vena interventricularis dorsalis cordis and the vena cordis magna were maintained intact, and a general view was obtained of the venous system of the septum.

The hearts injected for examination of the coronary system of veins in the papillary muscles were opened by HAMPERL's technique. From the external wall of the right and left ventricles a narrow strip was cut out, its pointed edge being directed towards the apex. In the strip, there remained the papillary muscles and the coronary veins draining them. The venous trunk lying beneath the epicardium of the strip was, as far as possible, maintained intact. The papillary muscles were, further, severed at their bases from the walls of the cardiac cavities and then examined radiographically.

For the purpose of examining the venae cordis minimae, tight rubber plugs were made for the ostia atrioventriculares. On the right side, they were introduced and placed in position through the orifice of the vena cava caudalis and, on the left side, through the terminal openings of the venae pulmonales. The aorta and the arteria pulmonalis were sealed with tight fitted cork stoppers, through which glass cannulae could be inserted. The coronary veins were ligated. By means of a syringe and a piece of rubber tubing the India-ink-gelatine mixture, warmed up to 38° C, was injected into the ventricles, both the syringe and the heart being again immersed into physiological saline of 38° to 40° C. The injection was continued, until the veins lying beneath the epicardium showed the appearance of the dye. The rubber tubing was ligated, and the heart was immersed into icy water for several

hours. Then the heart was again opened according to HAMPERL's technique, after which the cavity was gently washed to clear it from the injection material. This procedure brought the venae cordis minimae into view. The same technique was already used by UNGER.

Studies of the venae cordis minimae were, besides, made with histological preparations. The Hämatoxylin- van Gieson stain was employed. In the regions of the left and right ventricle the experiments were carried out on a material selected at random.

In order to expose the veins more distinctly, part of the heart was made transparent by the method of SPALTEHOLZ.

The glass bead technique employed by PRINZMETAL, SIMKIN, et al. was utilized in measuring the calibres of the anastomoses. Glass beads with a calibre ranging from 10 μ to 400 μ were prepared for this purpose by modifying the technique of SKLAREN (1934). A teaspoonful of glass beads were put into 200 ml of physiological saline mixed with 40 g of chrome-yellow dye and 0.7 g of gelatin. The mixture was warmed up to show 38° to 40° C. The atrioventricular orifices were sealed tightly, as described. Glass cannulae were introduced into the sinus coronarius and the two coronary arteries from the direction of the aorta. The cannulae were firmly tied with silk to the walls of the heart and lengthened by adding a piece of rubber tubing. The great vessels leaving the heart were sealed with tight cork stoppers, through which glass cannulae were inserted and directed to the cardiac cavities. The aorta contained three cannulae: two directed to the coronary arteries and one to the left ventricle. The vena cava caudalis had two cannulae: one directed to the sinus coronarius and the other to the right atrium. The arteria pulmonalis and the vena pulmonalis contained only one cannula each: the former inserted from the right ventricle and the latter from the left atrium. The well-mixed injection material was drawn into a heated syringe and immediately injected into one of the coronary arteries at a pressure of 200 mm Hg. 200 ml of the mixture was required for each experiment. It was transmitted on injection to the cardiac cavities and from there to the corresponding test tubes. The cavities were washed cautiously, and the mixture was sucked up with a pipette into the test tubes, care being taken that errors did not arise from these proce-

dures. From the venae cordis ventrales the glass beads were discharged into the right atrium. Where the vena cordis parva was the drainer of the right heart, the values for the right atrium were identical with those yielded by the venae cordis minimae of the right atrium. Ether and 10 % NaOH were added to the test tubes containing the discharged mixture of glass beads and dye, upon which the mixture was centrifuged. The glass beads were then sucked up with a pipette upon a glass slide. The size of the beads was measured by means of a microscope with a scale. In each specimen discharged the calibres of 100 of the largest beads were calculated, and the size of the largest bead was noted each time in the various tubes.

Calculations The percentages have been given with the error of 1 %. Wherever the various investigators have not stated their results in terms of percentages, these have been computed. In the author's material the percentages given are of a total of 160 cases, except where the comparison of the various groups has led to a separate computation of the percentage of each group of the material. The sinus coronarius has been examined in 100 adult hearts. As concerns the tables, the term »Present Material» in the column falling under the heading »Investigator» refers to the present work, and the figures given in that column indicate results from this work.

The evaluation of the results yielded by the present material has been carried out by aid of values obtained from a number of equations.

In estimating the mean values (m) and their standard errors [D(m)], as well as the standard deviations (σ) and their standard errors [D (σ)], the following equations have been applied:

$$m = \frac{1}{n} \sum f v \qquad D(m) = \frac{\sigma}{\sqrt{n}}$$

$$\sigma^2 = \frac{1}{n} \sum f v^2 \qquad D(\sigma) = \frac{\sigma}{\sqrt{2n}}$$

in which: n = number of cases
v = diameter (length, weight)
f = number of hearts, in which the diameter (length, weight) is v

The differences between the values obtained from these equations are classified by CRAMÉR (1945) into three degrees of magnitude, which are applied in this work (Table XII): a) fairly significant, when twice the standard error $<$ the difference obtained $<$ 2.6 times the standard error, b) significant, when 2.6 times the standard error $<$ the difference obtained $<$ 3.3 the standard error, c) highly significant, when 3.3 times the standard error $<$ the difference obtained.

The hearts were classified into given groups according to their weights, and comparisons were made between the mean values of the diameters of the corresponding veins in these groups. These investigations, conducted with a view to examining the relationship between the diameters of the veins and the increase of the heart weight, were carried out with the aid of the equations below (Table VIII):

$$r = \frac{m_{11}}{s_1 \cdot s_2} \qquad t = \sqrt{n-2}\,\frac{r}{\sqrt{1-r^2}}$$

$$m_{11} = \frac{1}{n}\sum f\,\nu_1\,\nu_2 - m_1\,m_2$$

$$\begin{cases} m_1 = \frac{1}{n}\sum f\,\nu_1 & s_1 = \frac{1}{n}\sum f\,\nu_1^2 - m_1^2 \\ m_2 = \frac{1}{n}\sum f\,\nu_2 & s_2 = \frac{1}{n}\sum f\,\nu_2^2 - m_2^2 \end{cases}$$

in which: r = coefficient of correlation
t = auxiliary figure for the table (CRAMÉR, p. 561) from which figure p. is obtained
p = figure indicating the random character of the results obtained
m_1 = mean of heart-weights
m_2 = mean of diameters
s_1 and s_2 = standard deviations of corresponding values
ν_1 = class of weights
ν_2 = class of diameters
m_{11} = auxiliary figure for determining the coefficient of correlation

The homogeneity of the values for the various age groups,

yielded by the glass bead experiments, is calculated from the following formula:

$$\chi^2 = m \cdot n \sum_{k=1}^{q} \frac{1}{\mu_k + \nu_k} \left(\frac{\mu_k}{m} - \frac{\nu_k}{n} \right)^2$$

in which: χ^2 = test of PEARSON (figure by use of which figure p was calculated from the table)

q —1 = degree of freedom

q = number of groups examined in materials to be compared

p = figure obtained from the table by means of the χ^2 — test and the figure for the degree of freedom (CRAMÉR, p. 559), indicating the homogeneity of the materials to be compared

μ_k = number of glass beads discharged in p.p. group k

m = total number of glass beads discharged in the p.p. group

ν_k = number of glass beads discharged in a. group k

n = total number of glass beads discharged in the a. group

The relative reliability of the results in estimating the homigeneity of the material may again be classified into the three different degrees given by CRAMÉR: a) fairly significant, when $1\% < p < 5\%$, b) significant, when $0.1\% < p < 1\%$, and c) highly significant, when $p < 0.1\%$ (Table XIII, XIV, and XV).

Nomenclature Employed in this Work

In the present investigation the nomenclature accepted in the *I.N.A.* has, as a rule, been employed of the veins already included in it. In order to prevent confusion, the terms used in this work for the branches of each coronary vein are given below. It may be pointed out, however, that the term vena cava cranialis dextra is here abbreviated to vena cava cranialis, as only one vena cava, the superior one, usually occurs. To distinguish from it the left superior vena cava, this vein was termed vena cava cranialis sinistra, as its presence in the human heart is very rare.

1. *Vena cordis magna (I.N.A.)* Its so-called ascending portion has been termed *ramus ascendens.* The tributaries of the vena cordis magna have been described in this work under the following titles: a) *rami ventriculi sinistri* is the term for all branches arising from the left ventricle and opening into the vena cordis magna either in the sulcus interventricularis ventralis cordis or in the sulcus coronarius, b) *rami ventriculi dextri* is the term indicating branches which take their origin from the ventral surface of the right ventricle and open into the vena cordis magna, c) *rami coni arteriosi* are venous branches which emerge from the conus arteriosus, d)*rami atrii sinistri* is the term for branches arising from the area of the left atrium, e) *rami auriculi sinistri* for branches which arise in the left auricle, and f) *rami septi ventrales* for branches which are distributed to the area of the septum interventriculorum.

2. *Venae dorsales ventriculi sinistri* (*I.N.A.*) Its branches are: a) *ramus dorsalis ventriculi 1,* and *ramus dorsalis ventriculi 2.*

3. *Vena obliqua atrii sinistri* (*I.N.A.*)

4. *Vena interventricularis dorsalis cordis* (*I.N.A.*) Its tributaries are: a) *rami ventriculi sinistri,* which originate in the region of the left ventricle, b) *rami ventriculi dextri,* which take their origin from the right ventricle, and c) *rami septi dorsales,* arising from the septum interventriculorum.

5) *Vena cordis parva* (*I.N.A.*) Its tributaries are as follows: a) *rami ventriculi dextri* arise from the region of the right ventricle, b) *rami atrii dextri* from the region of the right atrium, and c) *rami coni arteriosi* from the conus arteriosus.

6) *Venae cordis ventrales* (*I.N.A.*) Its branches have been termed: a) *rami ventriculi dextri,* b) *rami atrii dextri,* and c) *rami coni arteriosi.*

The accompanying figure (Fig. 3) will clarify the nomenclature. It shows that, where the same venous system has several prominent tributaries falling under the same title, the one lying nearest to the sulcus interventricularis dorsalis cordis has been termed 1, the next one 2, and so on.

As concerns the branches of the coronary veins, their nomenclature has aimed at indicating their localization. The branches of the coronary veins arising from the same area are identically named, irrespective of their opening into different venous trunks. Finding an exact term for each small radicle of the coronary veins

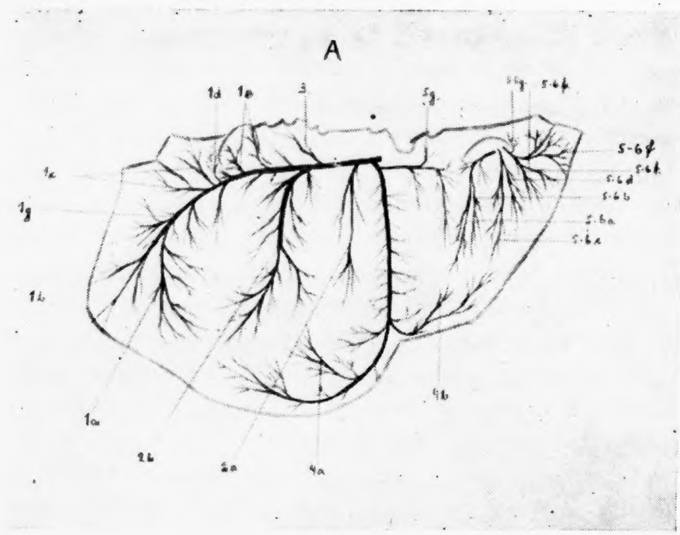
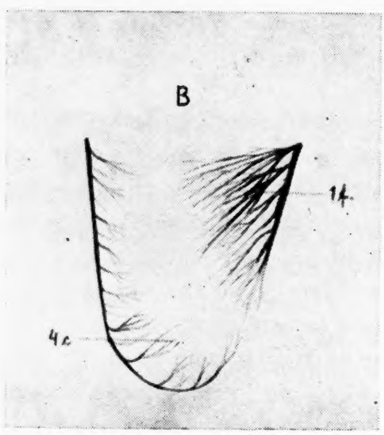


Fig. 3. Nomenclature employed in this Work.
A. Heart displayed on one plane. B. Septum interventriculorum. 1. vena cordis magna: 1a. rami ventriculi sinistri, 1b. rami ventriculi dextri, 1c. rami coni arteriosi, 1d. rami atrii sinistri, 1e. rami auriculi sinistri, 1f. rami septi ventrales, 1g. ramus ascendens. 2. venae dorsales ventriculi sinistri: 2a. ramus dorsalis ventriculi 1, 2b. ramus dorsalis ventriculi 2. 3. vena obliqua atrii sinistri. 4. vena interventricularis dorsalis cordis: 4a. rami ventriculi sinistri, 4b. rami ventriculi dextri, 4c. rami septi dorsales. 5. vena cordis parva, and 6. venae cordis ventrales: 5—6a. rami ventriculi dextri 1, 5—6b. rami ventriculi dextri 2, 5—6c. rami ventriculi dextri 3, 5—6.d. rami ventriculi dextri 4, 5—6.e. rami ventriculi dextri 5, 5—6f. rami coni arteriosi, 5—6g. rami atrii dextri.



is attended with difficulties, as they show great morphological variations, and the branches arising from the same area are not necessarily ramifications of the same venous trunk.

Although all text-books and manuals of anatomy already include the venae cordis minimae to the venae coronariae, the author has, to prevent confusion and to make the nomenclature clearer, used in this work the term coronary veins for all superficial veins and their branches included in the *I.N.A.*, while for the same reason, the venae cordis minimae have been described as a separate system of veins. The coronary veins (the vena cordis magna, the venae dorsales ventriculi sinistri, the vena obliqua atrii sinistri, the vena interventricularis dorsalis cordis, the vena cordis parva, and the venae cordis ventrales), have been dealt with as an independent system and the venae cordis minimae as another. An attempt has been made to define the concepts coronary arteries and coronary veins (the coronary vessels), as well as the concept venae cordis minimae (the Thebesian vessels). Despite of this formality in the nomenclature, the two systems of veins are considered to constitute a connected whole in this material, i.e. the venous network of the heart, the venae coronariae.

Abbreviations Employed

The following abbreviations have been employed in the present work:

B.N.A.	=	Baseler nomina anatomica
I.N.A.	=	Jenaer nomina anatomica
a.(A.)	=	group of adult subjects (over 18 yrs)
p.p.(P.P.)	=	group of post-partum subjects
♂	=	male material
♀	=	female material
L.V.	=	left ventricle
R.V.	=	right ventricle
No.	=	number
V.	=	vena
Vv.	=	venae
sin.	=	sinister
dx.	=	dexter
s.	=	seu
Lin.	=	Linie = 0.22 cm
Zoll	=	2.61 cm

Venae Coronariae

Sinus Coronarius

Frequency of Occurrence

The sinus coronarius is the common outlet of several venous trunks emerging from the cardiac muscle. In the material examined it was absent only in one of the post-partum subjects (0.5 %). The vena cava cranialis sinistra was present in this case. Other exceptional modes of emptying of the caval veins, described in the literature (e.g. MÖNCKEBERG, PEELE 1932, BIZZA), did not occur in the author's material. Nor were cases described by LECAT and SIDING encountred in this material. In the cases examined the vena cordis magna, the venae dorsales ventriculi sinistri, and vena interventricularis dorsalis cordis opened as separate stems into that part of the vena cava cranialis sinistra which lies in the sulcus coronarius, and the venae cordis ventrales opened directly into the right atrium. As concerns the frequency of occurrence of the vena cava cranialis sinistra, ADACHI has noted its presence in 7 of the 821 cases included in his material (1 %) and KEYES & KEYES (1925) in 2 (?) of 385 cases (0.5 %). In the material of RISCHBIETH (1914) and MCCOTTER (1916) its frequency is in the same proportion. ADACHI found that the occurrence of the vena cava cranialis sinistra was more frequent in the foetus than in the post-partum subject and increasingly infrequent with advancing age.

Localization

The sinus coronarius lies in the sulcus coronarius, between the left auricle and the terminal opening of the vena cava caudalis. In the material examined it always opened through that depression of the right atrium which is seen between the fossa ovalis and the orifice of the vena cava caudalis. Not even hearts with congenital lesions (coarctatio aortae and defectus septi interventriculorum) showed a sinus coronarius opening into the left atrium.

The sinus coronarius was always superficially placed in the sulcus coronarius, the ramus circumplexus of the left coronary artery lying beneath it on the floor of the groove. No arterial branches were seen running superficially to the sinus coronarius. The findings do not diverge from those of MOCHIZUKI.

Measures

On macroscopical inspection of the material, it becomes apparent that determination of the boundary-line between the sinus coronarius and the vena cordis magna cannot be based on

the difference in shape of the sinus coronarius nor on the localization of the terminal opening of the vena obliqua atrii sinistri. In MOCHIZUKI's material either the localization of the orifice of the vena obliqua atrii sinistri is obscure, or even the presence of this vein is subject to doubt in about 29 % of the cases. In 15 hearts (15 %) of the author's material the vena obliqua atrii sinistri did not open through the floor of the valvula Vieussenii, if this valve was present. In 37 hearts (37 %), furthermore, the vena obliqua atrii sinistri was not readily definable. In these cases the valvula Vieussenii was not definable at all. As a consequence, the longitudinal measure of the sinus coronarius was not even roughly determinable in 52 hearts (52 %). In 28 hearts (28 %) of the present material the opening of the vena obliqua atrii sinistri is found in the floor of the cusp of the valvula Vieussenii. In 2 of these hearts (2 %), however, there are several veins, which, each of them, may be regarded as the vena obliqua atrii sinistri. Only one of these veins opens into the pocket of the above-mentioned cusp. In the absence of this cusp in the material examined, the vena obliqua atrii sinistri may open beside the orifice of the sinus coronarius or into the vena cordis magna, close to the left margin of the left auricle. Hence, the fixation of the boundaries of the sinus coronarius was done by aid of the valvula Thebesii and the valvula Vieussenii alone, as basing it simultaneously on the valvula Vieussenii and the vena obliqua atrii sinistri was not feasible. The longitudinal measurements of the sinus coronarius were, therefore, carried out only in the presence of both valves, its two boundaries being the valvula Thebesii and the point of lateral attachment of the cusp of the valvula Vieussenii.

The sinus coronarius was thus measurable in 41 (41 %) of 100 adult hearts, — 24 ♂ and 17 ♀ —. Its long measure varied (♂ and ♀) from 20 to 60 mm, the mean being 39.6 $\pm$ 0.18 mm ($\sigma =$ 1.15 $\pm$ 0.13). GRUBER's and MOCHIZUKI's figures were »6 Lin. bis 2 Zoll» and 5 to 45 mm respectively, MECHANIK's, again, 23 to 46 mm. The divergences may be accounted for by different measuring techniques and, besides, by racial differences.

The diameter of the initial section of the sinus coronarius is measured at the valvula Vieussenii, and the terminal diameter immediately behind the valvula Thebesii. In the present material the latter ranges from 5 to 12 mm in adult (♂ and ♀) subjects, the

mean being 8.2 ± 0.2 mm ($\sigma = 1.77 \pm 0.17$). GRUBER's and TESTUT's figures were »5—6 Lin.» and 8 to 12 mm respectively. The figures reported by MOCHIZUKI, indicating the diameter of the middle section of the sinus coronarius, varied within the range of 7 to 14 mm. The observation made is that the more the limiting values in the present material deviate from the means, the more they steadily decrease in size.

Valves As already stated, the two valves coexist in 41 (41 %) of the 100 cases of this material, — 24 ♂ and 17 ♀ —. The presence of the valvula Thebesii alone is observed in 28 cases (28 %), — 14 ♂ and 14 ♀ —, and the valvula Vieussenii alone only in 2 ♂ cases (2 %). Valves, accordingly, occur in 71 hearts in all (71 %), the valvula Thebesii being present in 69 of them (69 %). KUDO's (1929) material comprises 37 hearts, 36 of which (97 %) show the presence of the valvula Thebesii. GRUBER, again, notes it in 88 hearts (88 %).

LAUENSTEIN (1876), CHIARI (1897), YETER (1929), and ADACHI describe a valvular structure in which the valvula Thebesii and the valvula venae cavae caudalis form a common cusp. According to MECHANIK, the latter of these valves may occasionally replace in part the valvula Thebesii in the case of its absence. These forms are not encountered in the present material.

The two valves were variable in size. In order to ascertain, whether these valves were able to prevent the so-called retrograde flow of blood from the right atrium into the sinus coronarius (the valvula Thebesii) or from the sinus coronarius into the vena cordis magna (the valvula Vieussenii), physiological saline was injected against them by the author. It was obvious from this experiment that both of the valves were able to prevent this retrograde flow. In this material the size of the valvula Thebesii varies as follows: 1) The valve covers the whole orifice of the sinus coronarius in 13 hearts (13 %), — 7 ♂ and 6 ♀ —. 2) It overlaps approximately half of the orifice in 56 hearts (56 %), — 31 ♂ and 25 ♀ —. 3) It is entirely absent in 31 hearts (31 %), — 19 ♂ and 12 ♀ —. The valvula Vieussenii is found to be present in 43 hearts (43 %), — 26 ♂ and 17 ♀ —. In 33 hearts (33 %), — 18 ♂ and 15 ♀ —, this valvula has only one cusp, while 10 hearts (10 %), — 8 ♂ and 2 ♀ —, are bicuspid in structure. When monocuspid, the valvula Vieussenii is seen to completely hide from view the orifice of the vena

cordis magna in 6 hearts (6%), — 4 ♂ and 2 ♀ —, but only half of the orifice in 27 hearts (27%), — 14♂ and 13 ♀ —. When bicuspid, the valvula Vieussenii covers the entire orifice of the vena cordis magna in 6 hearts (6%), — 5 ♂ and 1 ♀ —, but only half of it in 4 hearts (4%), — 3 ♂ and 1 ♀ —. Gruber encountered a monocuspid type of the valvula Vieussenii in 46 hearts (46%) and a bicuspid type in 31 hearts (31%). Ogo's corresponding figures were 5 (10%) and 4 (8%), the material consisting of 48 hearts; Mochizuki's, again, 46 (29%) and 11 (7%). Variations in the numbers of the cases, and probably also racial differences, account for the variations of the figures obtained. Marshall has always found the valvula Vieussenii to be of the bicuspid type, whereas Luschka has never made this observation. Mochizuki points out, »Die Valvula Vieussenii ist im allgemeinen klein. Selbst bei dem Vorhandensein von zwei Taschen ist die Klappe bei meinem Material niemals so gut entwickelt, dass sie den Rückfluss des Blutes vollständig aufhebt.» It is already noted by Gruber that the valvula Vieussenii may completely cover the orifice of the vena cordis magna, which was also observed in this material about both the monocuspid and the bicuspid types of the valvula Vieussenii.

If the two valves are coexistent, they are found to vary in size as follows: 1) The valvula Thebesii completely hides from view the terminal opening of the sinus coronarius, and the valvula Vieussenii simultaneously completely covers the orifice of the vena cordis magna in 7 hearts (7%) — 5 ♂ and 2 ♀ —, and only overlaps half of this orifice in 3 hearts (3%), — 1 ♂ and 2 ♀ —. 2) While the valvula Thebesii overlaps approximately half of the orifice of the sinus coronarius, the valvula Vieussenii simultaneously covers the entire opening of the vena cordis magna in 4 hearts (4%), — 3 ♂ and 1 ♀ —, and about half of this opening in 27 hearts (27%), — 15 ♂ and 12 ♀ —. It may be mentioned, further that, when present alone, the valvula Vieussenii covers the whole of the orifice of the vena cordis magna in 1 ♂ heart (1%) and approximately half of it in 1 ♂ heart (1%), whereas the valvula Thebesii, when alone, completely hides from view the terminal opening of the sinus coronarius in 3 hearts (3%), — 1 ♂ and 2 ♀ —, and approximately half of this opening in 25 hearts (25%), — 13 ♂ and 12 ♀ —. The valvula Thebesii was always found to be monocuspid in structure.

Other coronary veins also have presented rudimentary valvular folds guarding their terminal openings (e.g. GRUBER, OGO, MOCHIZUKI, MECHANIK). In the present material these rudimentary cusps occurred, too, but they were scarcely 1 mm in breadth. Only in one ♀ case (1 %) the valve was found to cover distinctly the terminal opening of the vena interventricularis dorsalis cordis. In this material the valves may, in most cases, be regarded as ridges formed by the junction at an acute angle of two intimae, and they probably seldom play any practical role in the blood circulation.

Types The localization of the terminal openings of the veins which empty into the sinus coronarius would seem to be significant from a surgical point of view.

The sinus coronarius as well as the vena cordis magna have been subjected to a number of surgical operations aiming at supplying the cardiac muscle with arterial blood through the coronary veins, where the coronary arteries are constricted or occluded (e.g. GROSS, BLUM, et al. 1937, GREGG & DEWALD 1938, THORNTON & GREGG 1939, BECK & MAKO 1941, ROBERTSON 1941, FAUTEUX 1946, BECK, STANTON, et al. 1948). Differentiation of the various types of the sinus coronarius has, therefore, been considered justified in this connection. In determining these types, attention has primarily been devoted to those main venous trunks (the vena cordis magna, the venae dorsales ventriculi sinistri, and the vena interventricularis dorsalis cordis) which are found to be present throughout the material examined: *Type 1.* The initial end of the sinus coronarius is the site of entrance of the vena cordis magna and the ramus dorsalis ventriculi 2, whereas the vicinity of its terminal opening shows the presence of the orifice of the vena interventricularis dorsalis cordis, which vein enters it either alone or jointly with the vena cordis parva. *Type* 2. The initial end of the sinus coronarius is the site of entrance of the vena cordis magna only, while the neighbourhood of its terminal opening shows, in this case also, the orifice of the vena interventricularis dorsalis cordis — which enters it alone or in company with the vena cordis parva — and the ramus dorsalis ventriculi. *Type 3.* The vena cordis magna and the ramus dorsalis ventriculi 2 have their entrances in the distal end of the sinus coronarius, while the vena interventricularis dorsalis cordis — alone or in company with the vena

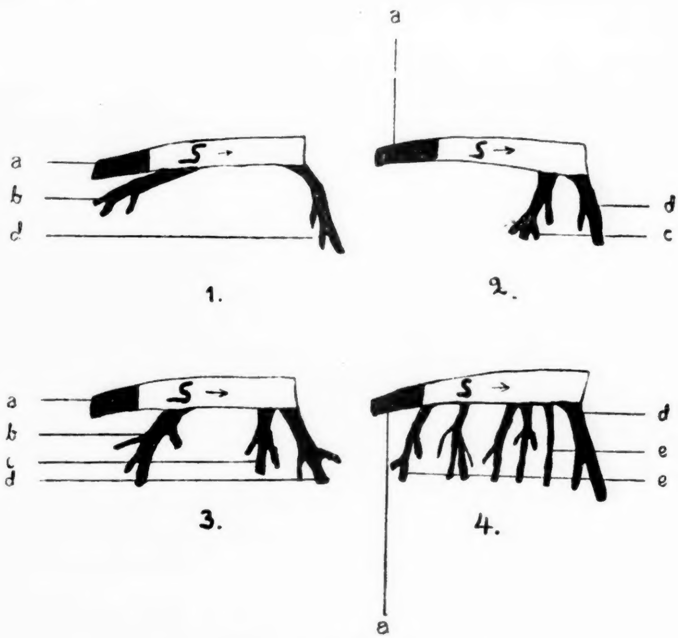


Fig. 4. The various types of the sinus coronarius.
1. The initial end of the sinus coronarius (S) is the site of entrance of the vena cordis magna (a) and the ramus dorsalis ventriculi 2 (b). The vena interventricularis dorsalis cordis enters (d) the sinus coronarius close to its terminal opening. 2. The vena cordis magna (a) opens alone into the initial end of the sinus coronarius, but both the ramus dorsalis ventriculi 1 (c) and the vena interventricularis dorsalis cordis (d) enter the sinus coronarius near its terminal opening. 3. The vena cordis magna (a) and the ramus dorsalis ventriculi 2 (b) have their entrances in the distal end of the sinus coronarius, while the vena interventricularis dorsalis cordis (d) and the ramus dorsalis ventriculi 1 (c) open close to the orifice of the sinus coronarius. 4. The distinction between this type and the previous one is that the venae dorsales ventriculi sinistri (e) have three or more outlets, which all open into the sinus coronarius.

cordis parva — and the ramus dorsalis ventriculi 1, open close to its orifice. *Type 4.* The distinction between this type and the previous one is that, in this case, the venae dorsales ventriculi sinistri have three of more separate outlets, which all open into the sinus coronarius.

Individual Coronary Veins

Each main venous trunk of the heart is an outlet of a most complicated system of veins. They, as well as their largest branches, lie beneath the epicardium, partly superficially, partly embedded in a layer of fatty tissue. Earlier investigations have mainly dealt with these superficial veins. Their distribution and course is very variable, the fact being that two hearts with an absolutely identical coronary venous system scarcely exist.

Vena Cordis Magna

The vena cordis magna is the outlet of an extensive venous system and is constantly present in the material examined. In the literature surveyed by the author, only HENLE (1868) refers to the possibility of its absence.

Opening

The vena cordis magna, after receiving its branches from the regions of the conus arteriosus, the left atrium and its auricle, as well as from the sulcus interventricularis ventralis cordis, opens into the sinus coronarius. In the material examined it is seen to open into the vena cava cranialis sinistra only in one heart (0,5%). The main trunk of the system of the vena cordis magna consists of its transverse section, which lies in the sulcus coronarius and is found, both in the literature surveyed and in the present material, to be invariably composed of a single stem. It commences in the place of union of this groove and the sulcus interventricularis ventralis cordis, in which it receives its fan-shaped system of branches, which is derived from the left atrium, the conus arteriosus, the right and left ventricles, and the septum interventriculorum. This stem of the vena cordis magna forms, by proceeding from the sulcus interventricularis ventralis cordis to the sulcus coronarius, the great curvature of the vena cordis magna, whereupon, running along the floor of the sulcus coronarius and passing beneath the left auricle, it takes at first a dorsal course, then curves to the right, either in the sulcus coronarius or in its immediate vicinity, and finally reaches the sinus coronarius. Throughout its course in the sulcus coronarius it receives a number of branches from the region of the left atrium and left ventricle.

The diameter of the orifice of the vena cordis magna varies in the material examined, ranging in the adult (♂ and ♀) from 4.0 to 8.0 mm, the mean being 5.6 ± 0.12 mm ($\sigma = 1.12 \pm 0.09$)

computed for a total of 100 hearts. The corresponding figures from GRUBER's material are »2—3.5 Lin.», and those from MOCHIZUKI's 3 to 7 mm.

Three different types may be distinguished, morphologically, only among those branches of the vena cordis magna which arise from the two ventricles. The classification is as follows: *Type 1.* The ramus ascendens is single-stemmed, when lying in the sulcus interventricularis ventralis cordis. The rami ventriculi dextri and sinistri are nearly equal in number and size, but less prominent than the other types of the material examined. *Type* 2. Not until their middle course in the sulcus interventricularis ventralis cordis, do the distal rami ventriculi dextri and sinistri unite to form a single-stemmed ramus ascendens. They are nearly equal in size, but they may extend inwards from this sulcus as far as halfway through the muscle substance of the two ventricles. The rami ventriculi dextri and sinistri are, in this case, distributed more over the surface of both ventricles. *Type 3.* The ramus ascendens is, in the main, formed by the union of the rami ventriculi dextri in the neighbourhood of the sulcus interventricularis ventralis cordis. The rami ventriculi sinistri may outgrow even the ramus ascendens, and they open partly into the region of the great curvature of the vena cordis magna and, partly, by several openings, into the transverse section of the vena cordis magna. The rami ventriculi sinistri of this type drain mainly the dorsal surface of the left ventricle. *Type 1* is found to be present in this material in a total of 59 hearts (37%), i.e. in 43 a. hearts, —24 ♂ and 19 ♀ —; in 16 p.p. hearts, — 7 ♂ and 9 ♀ —. *Type 2* is present in 76 hearts (47%), i.e. in 44 a. hearts, —27 ♂ and 17 ♀ —; in 32 p.p. hearts, 18 ♂ and 14 ♀ —. *Type 3* is encountered in 25 hearts (16%), i.e. in 13 a. hearts, — 6 ♂ and 7 ♀ —; in 12 p.p. hearts, — 5 ♂ and 7 ♀ —. *Types*

In the material examined the radicles of the ramus ascendens are seen to reach the apex in 37 hearts (23%), i.e. in 26 a. hearts, — 11 ♂ and 15 ♀ —; in 11 p.p. hearts, — 3 ♂ and 8 ♀ —. The same observation is made by MOCHIZUKI in 14 hearts (8 %). MOCHIZUKI's finding, that the radicles of the vena cordis magna do not continue from the ventral surface of the heart round the apex to the dorsal surface, is consistent with the findings from the author's own material.

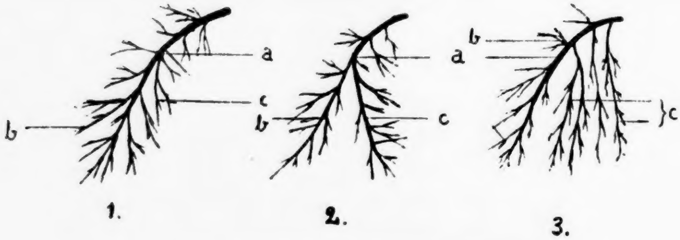


Fig. 5. The various types of the vena cordis magna.
1. The ramus ascendens (a) is single-stemmed. 2. In the sulcus interventricularis ventralis cordis the distal rami ventriculi dextri (b) and sinistri (c) unite to form a single-stemmed ramus ascendens. 3. The ramus ascendens is formed by the union of the rami ventriculi dextri, and the rami ventriculi sinistri open partly into the great curvature of the vena cordis magna.

Rami Septi Ventrales

No data on the coronary veins of the septum interventriculorum are encountered in the literature surveyed by the author. It would seem that this part of the coronary venous system has not been studied earlier in more detail. The rami septi ventrales constitute that part of the coronary venous system of the septum interventriculorum which opens, as a rule, into the ramus ascendens. Their course follows that of the muscle fibres. From the proximal portion of the septum interventriculorum they run towards the great curvature of the vena cordis magna and enter by well-marked openings, which may be as large as 2 mm into the proximal part of the ramus ascendens.

The distal branches, slender and diffuse, are directed from the ventral segment of the septum interventriculorum straight to the tributaries of the ramus ascendens. Differentiation of the rami septi ventrales into two types is feasible on the basis of their size and the extent of the area drained by them. Their size may be considerable in the proximal part of the septum interventriculorum, the area which they drain being nearly the whole of the septum interventriculorum. They may, on the other hand, be appreciable in number, but small in size, in which case they are principally distributed over the proximal and ventral portions of the septum interventriculorum (Fig. 7).

Rami Coni Arteriosi

From the region of the conus arteriosus a number of slender veins, the rami coni arteriosi, are also seen to be directed to the great curvature of the vena cordis magna. Around the bases of

the aorta and the arteria pulmonalis they form a system of veins, which is constantly present in this material. The lumen of their orifice is scarcely 1 mm in breadth, while according to Béraud, it may be as wide as 2 mm. Part of the rami coni arteriosi take their origin from the ventral surface of the heart and open into the rami ventriculi dextri, another part arising from the left margin of the conus arteriosus open as separate stems into the vena cordis magna, and those emerging from its dorsal region run along the groove between the conus arteriosus and the left atrium and terminate by entering into the vena cordis magna either as separate stems or as venous cords, in which case they occur intertwined with the rami atrii sinistri. In the author's material the veins described appear to form a network of veins around the conus arteriosus.

Ramii Atrii Sinistri

The rami atrii sinistri constitute the coronary venous system of the left atrium. They may enter the vena cordis magna from both in front of and behind the auricle. The ramii atrii sinistri, consequently, encircle the left auricle, their radicles lying close to one another in the area between the left auricle and the venae pulmonales. Their diameter scarcely measures 1 mm, and their number is very variable. No consistent morphological classification of these small veins into types has been feasible in this material.

Rami Auriculi Sinistri

The rami auriculi sinistri are tributaries of the coronary venous system of the left auricle and are of constant occurrence in the material examined. Their number ranges from 1 to 3. In the presence of a single-stemmed type, three branches can be defined, two of which running bilaterally from the left auricle, the third medially from its distal region. In the proximal part of the sulcus coronarius they unite to form a single small vein, which terminates by opening into the transverse segment of the vena cordis magna. In the presence of a two-stemmed type, the medial branch is absent, and the two stems open separately into the vena cordis magna. An additional type is encountered, in which each of the three branches of the single-stemmed type opens separately into the vena cordis magna. In the last two types, some of the rami atrii sinistri and rami auriculi sinistri may occasionally empty into the sinus coronarius by a common opening.

Relation to Arteries The relation of the main trunk of the vena cordis magna to that branch of the left coronary artery which lies in the sulcus coronarius is clear enough. In the region of the great curvature of the vena cordis magna most branches of the left coronary artery, as a rule, run beneath the stem of the vein, but there is always some prominent arterial branch also overlying it. The dorsal surface of the left ventricle does not show any strictly systematic relation between the arrangement of the branches of the vena cordis magna and the course of the descending rami of the left coronary artery. Corresponding arterial and venous branches may accompany one another, run independently or intertwined, which leads to the generalized conclusion that the larger venous branches in the surroundings of the sulcus coronarius are, on the whole, more superficially placed than the corresponding arteries. The small venous and arterial branches running on the dorsal surface of the left ventricle show no systematic interrelation in their distribution. The tributaries of the vena cordis magna drain that area of the heart which is supplied by the rami of the left coronary artery. These findings do not diverge from those of PIQUAND and MOCHIZUKI.

Venae Dorsales Ventriculi Sinistri The venae dorsales ventriculi sinistri drain in all cases examined that segment of the dorsal wall of the left ventricle which lies between the vena cordis magna and the vena interventricularis dorsalis cordis. Only in one a. ♂ heart of the whole material do its branches reach distally to the vena interventricularis dorsalis cordis, this being shorter than usual. In this case its radicles extend over the sulcus interventricularis dorsalis cordis as far as the distal ventral wall of the right ventricle.

Opening In the present material the system of the venae dorsales ventriculi sinistri opens as follows: 1) only into the sinus coronarius in 36 hearts (23%), i.e. in 29 a. hearts, — 17 ♂ and 12 ♀; in 7 p.p. hearts, — 5 ♂ and 2 ♀ —, 2) only into the vena cordis magna in 20 hearts (13%), i.e. in 8 a. hearts, — 3 ♂ and 5 ♀ —; in 12 p.p. hearts, — 4 ♂ and 8 ♀ —, 3) in no heart into the vena interventricularis dorsalis cordis alone, 4) simultaneously into the sinus coronarius and the vena cordis magna in 80 hearts (50%), i.e. in 48 a. hearts, — 33 ♂ and 15 ♀ —; in 32 p.p. hearts, — 14 ♂ and 18 ♀ —, 5) into the sinus coronarius and the vena interventricu-

laris dorsalis cordis in 7 hearts (4%), i.e. in 3 a. ♀ hearts; in 4 p.p. hearts, — 3 ♂ and 1 ♀ —, 6) into the vena cordis magna and the vena interventricularis dorsalis cordis in 5 hearts (3%), i.e. in 3 a. hearts, — 2 ♂ and 1 ♀ —; in 2 p.p. ♂ hearts, and ultimately, 7) simultaneously into the sinus coronarius, the vena cordis magna, and the vena interventricularis dorsalis cordis in 12 hearts (7%), i.e. in 9 a. hearts, — 2 ♂ and 7 ♀ —; in 3 p.p. hearts, — 2 ♂ and 1 ♀ —. The corresponding findings of other investigators are: 1) in GRUBER's material as a rule, in MOCHIZUKI's in 73 hearts (45 %), 2) in MOCHIZUKI's in 56 hearts (35 %), 3) in GRUBER's in 5 hearts (4 %), 4) in GRUBER's in 2 heart (2%), in MOCHIZUKI's in 13 hearts (8 %), and 6) in GRUBER's in 1 heart (1%).

In the material examined the diameters of the terminal openings of the venae dorsales ventriculi sinistri are indirectly proportional to the number of these veins, i.e. the greater their number the smaller the openings. The diameter of the opening varies in the adult within the range of 1 to 5 mm, and in MOCHIZUKI's material the corresponding figures range from 2 to 7 mm.

The number of the openings of the venae dorsales ventriculi sinistri system varies considerably. Single-stemmed outlets are encountered in 31 hearts (20%), i.e. in 20 a. hearts, — 11 ♂ and 9 ♀—; in 11 p.p. hearts, — 4 ♂ and 7 ♀ —, two-stemmed in 70 hearts (44%), i.e. 42 a. hearts, — 24 ♂ and 18 ♀ —; in 28 p.p. hearts, — 13 ♂ and 15 ♀ —, three-stemmed in 38 hearts (23%), i.e. in 25 a. hearts, — 14 ♂ and 11 ♀ —; in 13 p.p. hearts, — 8 ♂ and 5 ♀ —, and opening by multiple stems in 21 hearts (13%), i.e. in 13 a. hearts, — 8 ♂ and 5 ♀ —; in 8 p.p. hearts, — 5 ♂ and 3 ♀ —. MOCHIZUKI does not record any single-stemmed cases, but 13 two-stemmed (8%) and 129 three- or multiple-stemmed (81%). *Types*

In the material examined the venae dorsales ventriculi sinistri system extends as far as the apex in 40 hearts (25%), i.e. in 19 a. hearts, — 13 ♂ and 6 ♀ —; in 21 p.p. hearts, — 11 ♂ and 10 ♀ —; in MOCHIZUKI's material in 6 hearts (5%). It is spread over almost the whole dorsal wall of the left ventricle in 32 hearts (20%) of the author's material, i.e. in 14 a. hearts, — 11 ♂ and 3 ♀ —, in 18 p.p. hearts, — 11 ♂ and 7 ♀ —. It drains only a small area of the dorsal wall of the left ventricle in 5 hearts (3%), i.e. in 3 a. hearts, — 2 ♂ and 1 ♀ —; in 2 p.p. hearts, — 1 ♂ and 1 ♀ —, the

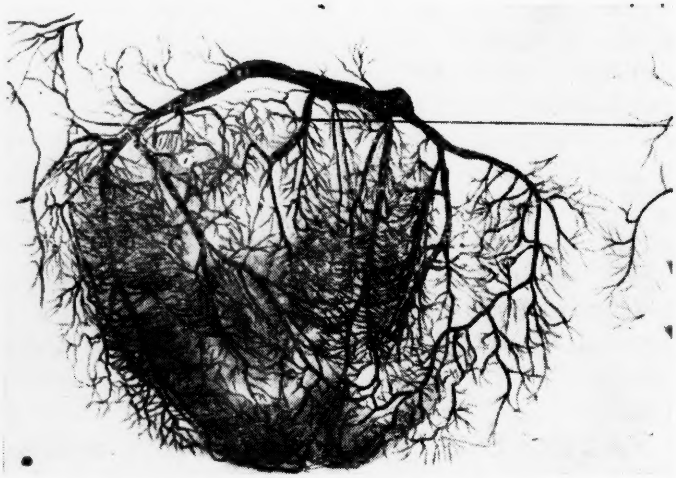


Fig. 6. The venae dorsales ventriculi sinistri drain only a small area of the dorsal wall of the left ventricle (a).

venae dorsales ventriculi sinistri system being in this case poorly developed, but, nevertheless, distinctly definable.

A striking feature in this research material is that the venae dorsales ventriculi sinistri system is always present, and that the system of the venae dorsales ventriculi sinistri may have a prominent single-stemmed outlet (Fig. 6). It is held by Mochizuki that the system of the venae dorsales ventriculi sinistri never occurs single-stemmed in its outlet, although his illustrations show some cases suggesting this type. Mochizuki comments further, »Unter 160 Herzen sind an 18 Herzen nur kleine Venen und keine ausgesprochene, als V. posterior ventriculi sinistri imponierende Vene zu finden, so dass man hier die V. posterior ventriculi sinistri als »fehlend» bezeichnen könnte». Mochizuki's view that the system of the venae dorsales ventriculi sinistri should always include multiple main stems, and that this venous system should always be termed in the plural, does not seem to be applicable to this material because of its stereotypy. This question, however, is subject to interpretation, the morphology of these veins being so variable that it is not always possible to determine, whether a vein is an independent part of this venous system or a prominent branch of the adjacent one, which extends

from its terminal opening as far as the dorsal wall of the left ventricle. The author's material, however, lends support to the view that the outlet of the venae dorsales ventriculi sinistri system may, in a way, be regarded as single-stemmed, and it appears poorly represented in only 5 hearts (3%) of this material. It, consequently, seems justified to consider this system of veins also independent, all the more, as it bears resemblance, morphologically, to the system of the venae dorsales ventriculi sinistri.

Relation to Arteries

Near the sulcus coronarius the main trunks of the venae dorsales ventriculi sinistri are, as a rule, more superficial than the corresponding arterial vessels. The smaller branches interlace in varying ways. The veins are not always seen to accompany the arteries. In the neighbourhood of the sulcus coronarius the arteries largely assume a ventral course being directed to the right towards the sinus coronarius. The findings are consistent with those of Piquand and Mochizuki.

Vena Interventricularis Dorsalis Cordis

The vena interventricularis dorsalis cordis is found to be invariably present in the material examined. Gruber reports that, in his material, he has once encountered two small veins replacing it, but this is not consistent with the author's findings. Its main trunk always lies in the sulcus interventricularis dorsalis cordis, from whose proximal end it curves towards the terminal opening of the sinus coronarius, emptying in its vicinity in all cases examined. It collects the blood from that part of the coronary venous system which is distributed over the surroundings of the apex, the region of the sulcus interventricularis dorsalis cordis, and the apical and dorsal parts of the interventricular septum. According to Mochizuki, the vena inerventricularis dorsalis cordis may present multiple stems almost as far as the proximal end of the sulcus interventricularis dorsalis cordis, in which it lies, but finally the stems unite to form a common outlet. This finding is made in 16 hearts (10%) of this material, i.e. in 9 a. hearts, — 3 ♂ and 6 ♀ —; in 7 p.p. hearts, — 6 ♂ and 1 ♀ —, and in 9 of Mochizuki's cases (6%). In the author's material, moreover, these venous trunks anastomose with one another giving rise to the »islets» discovered by Mochizuki. In other cases the vena interventricularis dorsalis cordis is to be considered single-stemmed already in the distal end of the sulcus interventricularis dorsalis cordis.

Opening As a number of text-books describe, the vena interventricularis dorsalis cordis opens, however, as a rule, through the floor of the valvula Thebesii, close to the orifice of the sinus coronarius. According to some investigators, the vena interventricularis dorsalis cordis may also open directly into the right atrium; GRUBER's finding is in 5 hearts (5%), PIQUAND's (9—10%), and MECHANIK's 3 hearts (2%). MOCHIZUKI could not find any evidence of this in his material, nor can it be observed in the present one. The vena interventricularis dorsalis cordis unites with the vena cordis parva just at its opening to form a common outlet in 72 hearts (45%), i.e. in 49 a. hearts, — 27 ♂ and 22 ♀ —; in 23 p.p. hearts, — 9 ♂ and 14 ♀ —, and in 22 hearts examined by MOCHIZUKI (14%). In 11 hearts of the author's material (7%), i.e. in 8 a.♀ hearts and in 3 p.p. hearts, —1 ♂ and 2 ♀ —, the ramus dorsalis ventriculi 1 and the vena cordis parva also open jointly into the vena interventricularis dorsalis cordis. The ramus dorsalis ventriculi 1 enters the main stem of the vena interventricularis dorsalis cordis in 13 hearts (8%), i.e. in 7 a. hearts, — 4 ♂ and 3 ♀ —; in 6 p.p. ♂ hearts.

In this material the lumen of its opening varies in size from 3 to 6 mm in adult subjects, the mean being 4.5 ± 0.11 mm ($\sigma = 1.1 \pm 0.08$), and in MOCHIZUKI's material from 2 to 8 mm.

Tributaries The proper branches of the vena interventricularis dorsalis cordis are the rami ventriculi sinistri, which lie in the area of the left ventricle, the rami ventriculi dextri, lying on the external wall of the right ventricle, and the rami septi dorsales, arising from the septum interventriculorum.

The vena interventricularis dorsalis cordis not infrequently receives its prominent superficial branches from the apical region alone, but in 9 hearts (6%), i.e. in 4 a. hearts, — 2 ♂ and 2 ♀ —; in 5 p.p. hearts, — 3 ♂ and 2 ♀ —, it receives branches of considerable size from both the right and left ventricle along its whole course in the sulcus interventricularis dorsalis cordis. The rami ventriculi sinistri are distinctly more prominent in 23 hearts (14%), i.e. in 16 hearts, — 5 ♂ and 11 ♀ —; in 7 p.p. hearts, — 4 ♂ and 3 ♀ —, the rami ventriculi dextri being similarly more prominent in 12 hearts (8%), i.e. in 7 a. hearts, — 4 ♂ and 3 ♀ —; in 5 p.p. hearts, — 4 ♂ and 1 ♀ —.

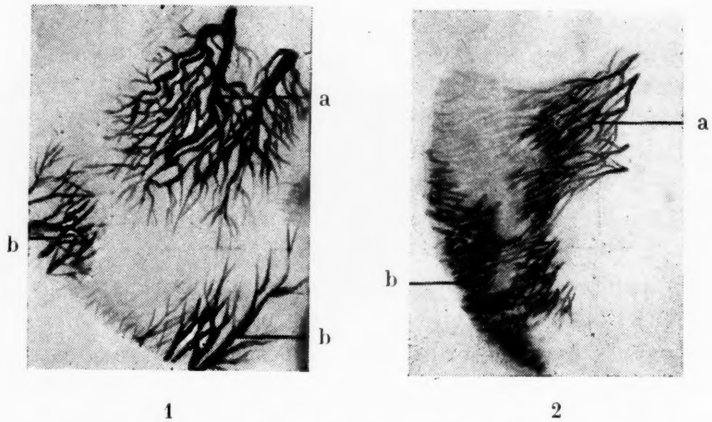


Fig. 7. The rami septi ventrales (a) and dorsales (b). The rami septi may be considerable (1) or fairly small (2) in size.

Rami Septi Dorsales

The rami septi dorsales drain principally the dorsal part of the septum interventriculorum and its apical region. Quite a number of small, short tributaries of the stem of the vena interventricularis dorsalis cordis extend, as a rule, to the proximal half of the septum interventriculorum. The more distally these branches are situated, the more prominent they are in size. Seldom do the rami septi dorsales exceed the midway of the proximal half of the septum interventriculorum, whereas in this region the rami septi ventrales are all the more prominent. In the distal half of the septum interventriculorum the rami septi dorsales are frequently numerous and spread over almost the entire apical region of the septum interventriculorum, the rami septi ventrales being here sparse and small in size. The variations of the septal branches of the coronary veins seem to be directly proportional to the variations in size of the corresponding venous trunks.

Relation to Arteries

In the sulcus interventricularis ventralis cordis, particularly in its proximal part, the most prominent arterial branches lie deeper than the corresponding venous tributaries. This difference in position is most striking, where the arteries and veins cross one another. On the dorsal and ventral surfaces of the cardiac apex the course of the tributaries of the vena interventricularis dorsalis cordis and that of the coronary arterial branches of the same areas are both variable, there being no perceptible conformity in

arrangement between the arterial and venous branches. These observations are consistent with MOCHIZUKI's findings.

Distribution of Veins in Apical Region

MOCHIZUKI emphasizes as his view that the vena interventricularis dorsalis cordis is the drainer of the apex of the heart. In the material examined by the author it drains the apex in 94 hearts (59 %), i.e. in 60 a. hearts, — 36 ♂ and 24 ♀ —; in 34 p.p. hearts, — 18 ♂ and 16 ♀ —, and in MOCHIZUKI's material in 145 hearts (91 %).

It is of interest to note that among the coronary veins only the branches of the vena interventricularis dorsalis cordis (the rami ventriculi sinistri and dextri) proceed from the sulcus interventricularis dorsalis cordis round the margin of the apex to the sulcus interventricularis ventralis cordis and its surroundings. In the present material they do not pass over the apex medially, but slightly laterally, on each side, receiving small radicles from the apical region. The rami ventriculi dextri curve, as a rule, to the sulcus interventricularis dorsalis cordis or its close vicinity, whereas the rami ventriculi sinistri are mostly found to remain within the apical area of the left ventricle. The radicles of the vena interventricularis dorsalis cordis reach the midway of the sulcus interventricularis ventralis cordis in 2 a. ♂ hearts (1 %), MOCHIZUKI's corresponding figure being 25 hearts (15 %). In the author's material they reach the distal region of the above sulcus in 97 hearts (60 %), i.e. in 62 a. hearts, — 36 ♂ and 26 ♀ —; in 35 p.p. hearts, — 19 ♂ and 16 ♀ —, MOCHIZUKI's finding being 119 hearts (74 %). In the author's material they also reach the apex in 56 hearts (35 %), i.e. in 33 a. hearts, — 18 ♂ and 15 ♀ —; in 23 p.p hearts, — 10 ♂ and 13 ♀ —, MOCHIZUKI's corresponding figure being 13 hearts (8 %). In the present material they reach the distal part of the sulcus interventricularis dorsalis cordis, but not the apex of the heart, in 5 cases (4 %), i.e. in 3 a. hearts, — 1 ♂ and 2 ♀ —; in 2 p.p. hearts, — 1 ♂ and 1 ♀ —, MOCHIZUKI's finding being 1 heart (1 %). MOCHIZUKI reports, moreover, that in 2 hearts (1 %) they extend even as far as the proximal end of the sulcus interventricucularis ventralis cordis.

There would seem to be grounds for adding that in this material the vena interventricularis dorsalis cordis and the vena cordis magna drain the apex simultaneously in 22 hearts (14 %), i.e in 19 a. hearts, — 7 ♂ and 12 ♀ —; in 3 p.p. ♀ hearts, and in

Mochizuki's material in 8 hearts (5%). The apex is drained simultaneously by the vena interventricularis dorsalis cordis, the vena cordis magna, and the venae dorsales ventriculi sinistri in 11 hearts (7%), i.e. in 5 a. hearts, — 3 ♂ and 2 ♀ —; in 6 p.p. hearts, — 2 ♂ and 4 ♀ —. The apex is drained by the vena cordis magna alone in 4 hearts (2%), i.e. in 2 a. hearts, — 1 ♂ and 1 ♀ —; in 2 p.p. hearts, — 1 ♂ and 1 ♀ —. The venae dorsales ventriculi sinistri system drains the apex in 29 hearts (18%), i.e. in 14 a. hearts, — 10 ♂ and 4 ♀ —; in 15 p.p. hearts, — 9 ♂ and 6 ♀ —, and in Mochizuki's material in 1 heart (1%).

Vena Obliqua Atrii Sinistri

The vena obliqua atrii sinistri is a small vein draining variably the external dorsal surface of the left atrium, i.e. the area which is enclosed between the left auricle, the opening of the pulmonary veins, and the septum atriorum. It is possible to determine the localization of its orifice, i.e. to determine, whether it opens into the sinus coronarius or the vena cordis magna, only where the boundary between the sinus coronarius and the vena cordis magna is definable macroscopically by aid of the valvula Vieussenii. It is found to open into the sinus coronarius in 42 a. hearts (42%), — 25 ♂ and 17 ♀ —. In 28 a. hearts (28%), — 18 ♂ and 10 ♀ —, the vena obliqua atrii sinistri opens into the pocket of the valvula Vieussenii. In 2 of these cases (2%) — 1 ♂ and 1 ♀ —, however, there are 2 to 3 veins opening side by side into the sinus coronarius, and any of these might be regarded as the vena obliqua atrii sinistri. The vena obliqua atrii sinistri opens into sinus coronarius at a considerable distance from the valvula Vieussenii in 14 a. hearts (14%), — 7 ♂ and 7 ♀ —. In the presence of the valvula Vieussenii, the vena obliqua atrii sinistri opens distinctly into the vena cordis magna in 1 ♂ heart (1%). In the absence of the valvula Vieussenii, the vena obliqua atrii sinistri opens variably, its orifice occuring occasionally in the sinus coronarius, close to its terminal opening, and occasionally in the vena cordis magna, even as far as the left margin of the left auricle. In Mochizuki's material the vena obliqua atrii sinistri opens into the vena cordis magna in 2 hearts (1%) and only seemingly into it in 18 hearts (12%). In the material examined the vena obliqua atrii sinistri is absent in 5 hearts (3%), i.e. in 4 a. hearts, — 2 ♂ and 2 ♀ —; in 1 p.p. ♂ heart —, and in Mochizuki's material in 25 hearts (16%). The

present material shows, further, in place of it, in 37 hearts (23 %), i.e. in 28 a. hearts, — 19 ♂ and 9 ♀ —; in 9 p.p. hearts, — 5 ♂ and 4 ♀ —, two or more small veins, which would seem to correspond to the rami atrii sinistri. Only in 118 hearts of the author's material (74%), i.e. in 68 a hearts, — 36 ♂ and 32 ♀ —; in 50 p.p. hearts, — 24 ♂ and 26 ♀ —, can the vena obliqua atrii sinistri be distinctly defined; MOCHIZUKI's corresponding figure is 135 (84 %).

According to the theories presented in the literature (e.g. GRUBER, MARSHALL, ADACHI), the vena obliqua atrii sinistri may be subject to degenerative changes, showing variations in structure according to the various stages of cardiac development. In the foetal period it may be prominent in size, but may later undergo weakening. The present material seems to be suggestive of such a trend of development, but no conclusive evidence can be obtained. According to MARSHALL, the vena obliqua atrii sinistri is constantly present in every heart, while GRUBER finds it almost invariably in children and in $^5/_8$ of a. hearts (63 %). In the author's material the vena obliqua atrii sinistri is found to be equal in size to the vena cordis magna in 2 hearts (2 %), — i.e. in 1 a. ♂ heart and in 1 p.p. ♀ heart —.

Vena Cordis Parva

The vena cordis parva is the main trunk of the venous system which drains the ventral wall of the right ventricle. It opens into the sinus coronarius, as a rule. Its course and area of distribution are very variable, although constantly limited to the right side of the heart, from which region it may variably receive a number of branches, i.e. the rami ventriculi dextri, the rami coni arteriosi, and the rami atrii dextri. Assuming a varying course, these rami ascend to the sulcus coronarius or its vicinity and unite to form a common outlet, the vena cordis parva, which proceeds in the sulcus coronarius or its neighbourhood towards the orifice of the sinus coronarius and terminates by opening into its immediate vicinity, either separately or in company with the vena interventricularis dorsalis cordis. In the author's material the presence of the vena cordis parva can be demonstrated in a total of 98 hearts (61 %), i.e. in 66 a. hearts, — 36 ♂ and 30 ♀ —; in 32 p.p. hearts, — 13 ♂ and 19 ♀ —. It is also encountered by MOCHIZUKI in 56 cases (35 %).

Opening

The localization of the opening of this vein is variable. In 25

hearts (15%) of the present material, i.e. in 17 a. hearts, — 9 ♂ and 8 ♀ —; in 8 p.p. hearts, — 3 ♂ and 5 ♀ —, it opens as a separate stem into the sinus coronarius, between the entrance of the vena interventricularis dorsalis cordis and the orifice of the sinus coronarius the corresponding figure in Mochizuki's findings is 34 hearts (21%). In one p.p. ♂ case (1%) it opens directly into the right atrium. Mochizuki does not concur in this finding, whereas Gruber, Piquand, and Mechanik have met similar cases showing a direct opening of the vena cordis parva into the right atrium, although seldom situated close to the orifice of the sinus coronarius. In 72 hearts (45%), i.e. in 49 a. hearts, — 27 ♂ and 22 ♀ —; in 23 p.p. hearts, — 9 ♂ and 14 ♀ —, of the present material the vena cordis parva and the vena interventricularis dorsalis cordis unite to form a common outlet, this being also Mochizuki's finding in 22 cases (14%) of his material.

The lumen of the opening of the vena cordis parva (Type 1) ranges in the adult from less than 2 mm to 5 mm, the mean being 3.3 $\pm$ 0.15 mm ($\sigma = 0.84 \pm 0.11$).

As a system, the vena cordis parva may be classified into 2 types as follows: *Type 1.* The vena cordis parva drains exclusively the major portion of the ventral surface of the right ventricle. The venae cordis ventrales are absent (Fig. 8). *Type 2.* The ventral surface of the right ventricle is simultaneously drained by two systems: the venae cordis ventrales and the vena cordis parva, the latter being less prominent (Fig. 8). *Types*

Type 1 corresponds most nearly to the one termed »sehr stark» by Mochizuki. In the present material it occurs in 53 hearts (33%), i.e. in 31 a. hearts, — 19 ♂ and 12 ♀ —; in 22 p.p. hearts, — 9 ♂ and 13 ♀ —; in Gruber's material in 8: 92 (8%), in Mochizuki's material in 18 hearts (12%), and in Piquand's material in one out of 5 hearts (20%). The tributaries of the vena cordis parva are in this type the rami coni arteriosi, the rami atrii dextri, and the rami ventriculi dextri. From the conus arteriosus the rami coni arteriosi enter the vena cordis parva in the sulcus coronarius, either separately or by slender stems, which they have in common with the rami atrii dextri and the rami ventriculi dextri 5 and 6 after uniting with them. As early as in the right end of the sulcus coronarius these branch groups may unite to form a single-stemmed outlet for the vena cordis parva system, and this outlet sub-

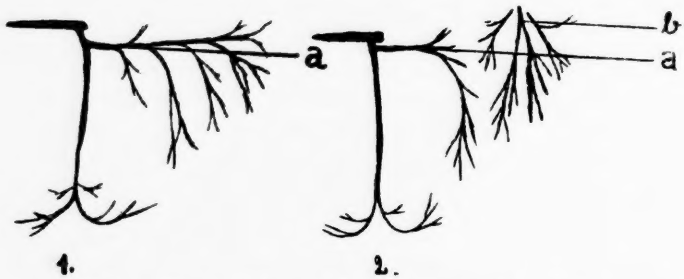


Fig. 8. The two types of the vena cordis parva.
1. The vena cordis parva (a) drains alone the major portion of the ventral surface of the right ventricle. 2. The ventral wall of the right ventricle is drained by two systems: the vena cordis parva (a) and the venae cordis ventrales (b).

sequently receives the rami ventriculi dextri from the ventral surface of the right ventricle and, finally, the rami atrii dextri from the neighbourhood of the terminal opening of the vena cava caudalis. The rami coni arteriosi, the rami atrii dextri, and the rami ventriculi dextri may run as separate stems in the sulcus coronarius or its surroundings as far as near the margo acutus dextri and only then unite to form variably the main trunk of the vena cordis parva system.

Type 2. is present in the author's material in 45 hearts (28%), i.e. in 35 a. hearts, — 17 ♂ and 18 ♀ —; in 10 p.p. — 4 ♂ and 6 ♀ —, and in Mochizuki's material in 38 hearts (23%). It corresponds to the types »stark» and »schwach» distinguished by Mochizuki. The variety corresponding to Mochizuki's »schwach» is present in 35 hearts (22%), i.e. in 25 a. hearts, — 12 ♂ and 13 ♀ —, 10 p.p. hearts, — 4 ♂ and 6 ♀ —, and in 15 of Mochizuki's own cases (9%).

The other variety includes in the vena cordis parva system the rami ventriculi dextri 1, or 1 and 2, but not the rami ventriculi dextri 3. The vena cordis parva system extends in this case along the margo acutus dextri across the ventral surface of the right ventricle neare the apex in 10 a. hearts (6%), — 5 ♂ and 5 ♀ —. In Mochizuki's type »stark» the vena cordis parva system is also joined by the rami ventriculi dextri 2 and occasionally even 3, such cases occurring 23 times (14%). The stem of the vena cordis parva, however, does not always follow the course of the sulcus coronarius. In the cases presented before it is directed in 6 a.

hearts (4%), — 3 ♂ and 3 ♀ —, from the neighbourhood of the sinus coronarius straight to the apex, its branches being continued round the margo acutus dextri scarcely anywhere else than in the apical region of the right ventricle.

Venae Cordis Ventrales

The venae cordis ventrales drain the ventral surface of the right ventricle. The only distinction between it and the vena cordis parva is that the terminal openings of the venae cordis ventrales in the right atrium are situated at the base of the right auricle, slightly proximally to the sinus coronarius or in the neighbourhood of the vena cava cranialis. The size of the openings of the venae cordis ventrales system is directly proportional to the number of these openings. The diameters range from 1 mm up to 2.5 mm in adult subjects.

Opening

The present material yields the finding that not one of the main trunks of the venae cordis ventrales system has its opening in the dorsal wall of the right atrium. These trunks open constantly, although variably, into the distal dorsal region of the right auricle. According to Mochizuki's findings, they enter the right atrium through the distal dorsal wall in 16 hearts (10%), the orifices being localized on the left side of the right auricle, between it and the opening of the vena cava caudalis. Davida finds that prominent coronary veins, lying on the ventral surface of the right ventricle, empty into the vena cava cranialis, close to its orifice. The arrangement described is encountered by the author in 1 a. heart (1%) and by Mochizuki in 2 hearts (1%).

Types

The venae cordis ventrales are absent in 53 hearts (33%) of the present material. Gruber does not give any figures, but Mochizuki records 18 hearts (12%) devoid of these veins. When present in the author's material, the system of the venae cordis ventrales has a variable appearance. It may open by a short single-stemmed outlet into the right atrium and does so in 10 hearts (7%), i.e. in 6 a. hearts, — 4 ♂ and 2 ♀ —; in 4 p.p. hearts, — 2 ♂ and 2 ♀ —; Mochizuki's corresponding figure is 50 hearts (31%). It may also open by two separate stems and does so in 18 hearts (11%), i.e. in 11 a. hearts, — 6 ♂ and 5 ♀ —; in 7 p.p. hearts, — 5 ♂ and 2 ♀ —; Mochizuki's finding is 52 hearts (33%). It may, further, terminate by dividing into three outlets, and does so in 32 hearts (20%) in the present material, i.e. in 17 a. hearts, — 11

♂ and 6 ♀ —; in 15 p.p. hearts, — 9 ♂ and 6 ♀ —; MOCHIZUKI's corresponding figure is 34 hearts (21 %). Finally, it may divide into four or multiple terminal stems and is found to do so in 2 p.p. hearts (1 %), — 1♂ ans 1 ♀ —; MOCHIZUKI's material shows 6 hearts (4 %) of this type.

Course of Distribution of Branches The rami ventriculi dextri, the rami atrii dextri, and the rami coni arteriosi constitute a systemic unity of veins, in which the rami coni arteriosi and the rami atrii dextri form multiple slender cords of veins directed towards the sulcus coronarius, where the rami ventriculi dextri also gather separately. In the sulcus coronarius, or variably in its neighbourhood, the branches draining the right atrium are placed proximally and the branches draining the right ventricle distally, particularly in the regions adjacent to the conus arteriosus and the margo acutus dextri. The course of these branches follows the distribution of the correspondingly termed branches of the vena cordis parva as far as near the sulcus coronarius, but on approaching it, they assume a separate course. The branches of the venae cordis ventrales draining the right ventricle cross superficially the sulcus coronarius at right angles, being simultaneously directed to the base of the right auricle and varying in their course according to their inconstantly placed terminal openings. The rami ventriculi dextri 1, consequently, often turn at an obtuse angle to the left, and the rami ventriculi dextri 2 and 3 cross at right angles the sulcus coronarius, while the rami ventriculi dextri 4 to 6 curve from the ventral surface of the heart to the right towards the sulcus coronarius.

A certain morphological arrangement can, nevertheless, be noted in the venae cordis ventrales system. The area where the radicles of the rami ventriculi dextri are localized forms a continuous zone, almost parallel to the sulcus interventricularis ventralis cordis. The length of the rami ventriculi dextri, accordingly, always bears a given relation to the sulcus interventricularis ventralis cordis. Not infrequently the rami ventriculi dextri 1 and 2 extend almost as far as the sulcus interventricularis ventralis cordis, whereas the rami ventriculi dextri 3 to 6 do not reach this groove, and the terminal openings of the rami ventriculi dextri 6 are the remotest.

Relation to Arteries The vena cordis parva lies, as a rule, superficially in the sulcus

coronarius, but its branches may be embedded deep in the fatty tissue. The venous tributaries are usually more superficial in the surroundings of the sinus coronarius. But in the region of the conus arteriosus the fairly slender veins penetrate to the fatty tissue, while the descending large branches of the right coronory artery occur more superficially in the neighbourhood of the sulcus coronarius. In the presence of the venae cordis ventrales in the region of the margo acutus dextri, the rami ventriculi dextri lie more superficially in the sulcus coronarius. They cross superficially the curving branch of the right coronary artery, but on approaching the conus arteriosus, they lie beneath this arterial branch. On the ventral surface of the right ventricle the interrelation of the venous and arterial branches is again variable. The descending branches of the right coronary artery invariably supply the area drained by the vena cordis parva and the venae cordis ventrales, but in the apical region the arteries are seen to extend farther than the sulcus interventricularis ventralis cordis more frequently than the rami ventriculi dextri. The rami ventriculi dextri may closely follow the distribution of each corresponding artery, but more frequently the corresponding arterial and venous branches show no conformity in their arrangement. The essential feature is that the vena cordis parva and the venae cordis ventrales systems bear identical relations to the right coronary artery and its branches. The same observations are made by PIQUAND and MOCHIZUKI.

Coronary Venous System as a Whole

In the previous the morphology of the so-called main trunks of the coronary veins has been the chief consideration. The object of the following is to devote attention to the morphology of the coronary venous system as a whole. In order to obtain a clear general picture of this whole, a number of divisions have been carried out.

Various Divisions

The coronary venous system can be divided into two halves by a plane of intersection, which follows the axis of the septum interventriculorum. In the borderline zone between the right and left halves, i.e. in the sulcus interventricularis ventralis cordis and dorsalis cordis, as well as in the septum interventriculorum, given veins and venous branches are always present, i.e. the vena interventricularis dorsalis cordis, the ramus ascendens (the vena cordis magna), and the rami septi ventrales and dorsales. They may be termed veins of the borderline zone. The coronary venous system, accordingly, may be divided into three parts: 1) the so-called coronary venous system of the borderline zone, 2) the left coronary venous system, and 3) the right coronary venous system.

Coronary Venous System of Borderline Zone

In the author's material the veins of the borderline zone lie in the sulcus interventricularis ventralis cordis and dorsalis cordis as well as in the septum interventriculorum, draining simultaneously both the entire dorsal wall of the right ventricle and the entire ventral wall of the left ventricle. The veins of the borderline zone do not consist of terminal trunks only, the fact being that the radicles of the vena interventricularis dorsalis cordis in the sulcus interventricularis ventralis cordis anastomose with those of the ramus ascendens. The vena cordis magna forms a direct continuation of the ramus ascendens. The heart, consequently, is embraced by a ring-like central venous channel, which opens into the sinus coronarius and also receives numerous tributaries from deep layers of the borderline zone, i.e. the rami septi ventrales and dorsales. At the mid-height of the septum interventriculorum, there is an area of bifurcation: the rami septi ventrales are directed towards the great curvature of the vena cordis magna, the rami septi dorsales, again, towards the sulcus interventricularis dorsalis cordis.

Fig. 9. The ring-like central venous channel of the borderline zone. The bifurcation area (A) of the septum interventriculorum; a. vena cordis magna, b. vena interventricularis dorsalis cordis

The superficial margins of the borderline zone, as well as those regions of the ventral surface of the right ventricle which are adjacent to the sulcus interventricularis dorsalis cordis and ventralis cordis, are drained by the rami ventriculi dextri, the corresponding parts of the dorsal surface of the left ventricle being drained by the rami ventriculi sinistri. The rami ventriculi dextri and sinistri running in the sulcus interventricularis dorsalis cordis open into the vena interventricularis dorsalis cordis, whereas those of the correspondingly termed branches in the sulcus interventricularis ventralis cordis which lie in the distal end of the groove, frequently open into the vena interventricularis dorsalis cordis, and those lying proximally open into the ramus ascendens. An additional bifurcation area is thus formed in the sulcus interventricularis ventralis, between the distal and proximal rami ventriculi sinistri and dextri, part of the venous blood being transmitted along the ramus ascendens up to the great curvature of the vena cordis magna, part of it descends along the branches of the vena interventricularis dorsalis to the apex of the heart.

The localization of the bifurcation areas varies with the length of the corresponding venous branches. The study of this part of the coronary venous system has not led to any classification into types, as the hearts of the material are almost similar in this respect, with the exception of variatons in the position of the bifurcations.

Left Coronary Venous System

The left coronary venous system is not so well-defined as that of the borderline zone. It may be divided into the venous system of the left atrium and the left ventricle. Their main trunks are

the vena cordis magna and the sinus coronarius, both of which lie in the sulcus coronarius. It would seem justified to regard this complex as the main outlet of the entire coronary venous system of the left heart. Macroscopically, there is practically no difference to be noted between the sinus coronarius and the vena cordis magna of the author's material, as the valvula Vieussenii is absent, and the vena cordis magna shows only a gradual widening and change in continuing into the sinus coronarius.

The general morphology of the branches arising from the left atrium and auricle, proximally to the sulcus coronarius, is as follows: small veins, varying in number, enter the vena cordis magna and the sinus coronarius throughout the whole length of their stems.

Many more variations are shown by the morphology of the venous system occupying the dorsal surface of the left ventricle, this being the most prominent part of the entire coronary venous network. The rami ventriculi sinistri are distributed over the marginal regions of the left dorsal wall, the venae dorsales ventriculi sinistri over the mid-area. Between these radicles, there forms again an area of bifurcation, typical, although rather obscure: the venous blood is directed by the rami ventriculi sinistri towards both the sulcus interventricularis dorsalis cordis and ventralis cordis, while the venae dorsalis ventriculi sinistri pass it towards the sulcus coronairus, straight into the transverse portion of the vena cordis magna and into the sinus coronarius.

The left coronary venous system may be classified into two different types according to their course of distribution: *Type 1.* The venae dorsalis ventriculi sinistri system is prominent, and its main trunks are directed at right angles to the sulcus coronarius. The middle dorsal surface of the left ventricle is covered by a wide-stemmed network of coronary veins. The rami ventriculi sinistri are not so fully developed and extend chiefly to the borderline zone. The main direction of these branches is towards the sulcus coronarius. This type is seen in 32 hearts (20 %), i.e. in 14 a. hearts, — 11 ♂ and 3 ♀ —; in 18 p.p. hearts, — 11 ♂ and 7 ♀ —. *Type 2.* The rami ventriculi sinistri also drain the major part of the dorsal wall of the left ventricle. Its mid-area shows a less abundant supply of veins, whenever the venae dorsales ventriculi sinistri system is insignificant. The course of distribution is

radiate. Type 2 is encountered in 5 hearts (4%), i.e. in 3 a. hearts, — 2 ♂ and 1 ♀ —; in 2 p.p. hearts, — 1 ♂ and 1 ♀ —. The rest of the cases are only variable modifications of this type.

The Right Coronary Venous System

The coronary venous system of the right heart presents the most variable morphology. It opens: 1) by a single-stemmed outlet into the sinus coronarius system (the vena cordis parva), 2) by two or more main stems directly into the right atrium (the venae cordis ventrales), or 3) by a single stem into the sinus coronarius system (the vena cordis parva) and, simultaneously, by one or more outlets into the right atrium (the venae cordis ventrales). The first two types of arrangement have already been dealt with. The third one constitutes the most interesting detail of the coronary venous system.

The coronary venous system formed by the coexistent vena cordis parva and venae cordis ventrales can in this material be classified into four different types: *Type 1.* The vena cordis parva is coexistent with a single-stemmed system of the venae cordis ventrales. This type is present in 8 hearts of the author's material (5%), i.e. in 6 a. hearts, — 2 ♂ and 4 ♀ —; in 2 p.p. ♀ hearts. — *Type 2.* The vena cordis parva is coexistent with a two-stemmed system of the venae cordis ventrales. This type is encountered in 19 hearts (12%), i.e. in 16 a. hearts, — 10 ♂ and 6 ♀ —; in 3 p.p. hearts, — 2 ♂ and 1 ♀ —. *Type 3.* The vena cordis parva and a three-stemmed venae cordis ventrales system are simultaneously present. Type 3 is encountered in 17 hearts (10%), i.e. in 13 a. hearts, — 5 ♂ and 8 ♀ —; in 4 p.p. hearts, — 2 ♂ and 2 ♀ —. *Type 4.* The vena cordis parva is coexistent with a four- or multi-stemmed venae cordis ventrales system. This type is represented in 1 p.p. ♀ heart (1%).

Theory of Reduction

Piquand and Mechanik have noted the diffuse arrangement of the venous system of the right heart, as described, and have put forward the view that the coronary system of the right heart is still in a stage of development. The ultimate result of this development would be the definite separation of its main trunks from the sinus coronarius. Even the vena interventricularis dorsalis cordis would, finally, open directly into the right ventricle. Mechanik presents these views already in a finished form. The development of the coronry veins is divided by Mechanik into 2 stages: the

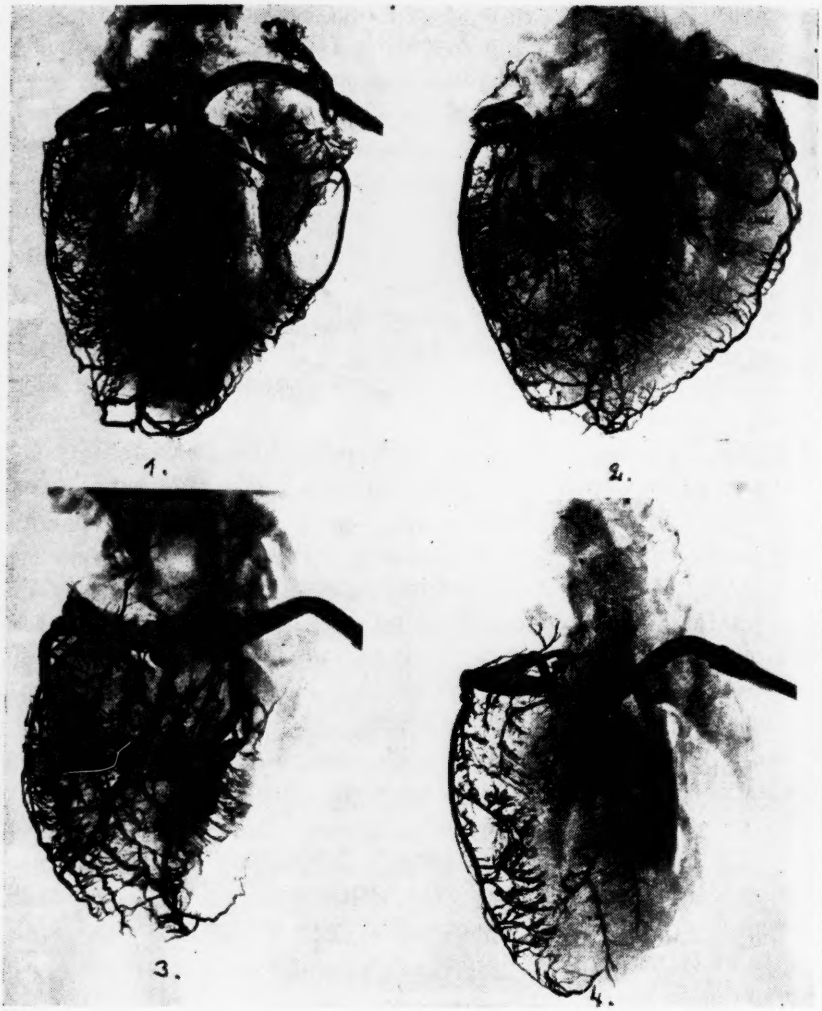


Fig. 10. The theory of reduction.
1. The »venae cordis ant. dextrae» divide from the sinus coronarius. 2. The »vena marginalis dextra» also divides from it, but the vena cordis parva still remains a tributary of the sinus coronarius. 3. All veins arising from the ventral surface of the right ventricle open directly into the right atrium. 4. The vena interventricularis dorsalis cordis also opens directly into the right atrium.

»embryonic» and the »postembryonic». In the »embryonic» stage the work performed by the right and left ventricles, respectively, are equal in amount, and their walls are of equal thickness. Only the main venous trunks opening into the sinus coronarius are present at this stage; the whole network of the coronary veins empties into the sinus coronarius. In the »post embryonic» stage the left ventricle of the heart out-grows the right one, and the increase of its burden of work is greater then the one presented by the right ventricle. As the sinus coronarius is no longer capable of receiving alone the increased volume of blood discharged by the coronary veins, a number of tributaries gradually break away from it (Fig. 10). The figures obtained by various investigators for this gradual reduction of the number of the tributaries are given in the accompanying table (Table VI).

Table VI: Gradual Reduction

Investigator	Stage 1	Stage 2	Stage 3	Stage 4
PIQUAND	14—17 %	40 %	10—11 %	
MECHANIK	15—20 %	50—60 %	10 %	1—2 %
Present Material ..	6 %	22 %	39 %	0 %

MECHANIK'S investigations do not give any percentages to show the differences between »embryonic» and »postembryonic» cases. The following Table VII presents a grouping of the author's material on the same basis of division.

Table VII: Reductions Shown by Present Material

Age Groups	Stage 1	Stage 2	Stage 3	Stage 4
P.P.	0 %	17 %	48 %	0 %
A.	9 %	25 %	34 %	0 %

MECHANIK'S theory of an increased blood circulation in the walls of the left ventricle, is interesting. It would seem justified in this connection to pay attention to the diameters of the terminal openings of the coronary venous trunks. Only one-stemmed coronary veins in a. hearts will be considered. The results obtained are

presented in the accompanying table, from which it would appear that the diameters of the vena cordis magna and of the vena interventricularis dorsalis cordis increase with the weight of the heart. The values are given in terms of mean values in this table (Table VIII).

Table VIII: Diameters of Terminal Openings in Relation to Heart Weights

Vein	200—250 gr	251—300 gr	301—350 gr	r	t	p
Vena cordis magna	5.0 mm	5.3 mm	5.6 mm	0.29	3.04	1.0%
Vena interventricularis dorsaalis cordis..........	3.8 »	4.2 »	4.8 »	0.35	3.72	0.1%
Vena cordis parva	3.5 »	2.3 »	3.4 »	—	—	—

Types of General System of Coronary Veins

The individual trunks of the coronary venous system show great variations morphologically, and so do the venous systems of the two halves of the heart. To classify the general coronary system into definite main types is, consequently, attended with considerable difficulty.

It is to be supposed, however, that a classification on this line might be of certain interest from the point of view of anthropology. An attempt to carry out such a classification has, therefore, been made by the author. According to MECHANIK's reduction theory, his material shows four different stages of development. The present division is based on the central idea of this theory somewhat modified; i.e. the development is not considered a reduction phenomenon, but a morphological one.

Type 1. The general system of the coronary veins empties into the sinus coronarius. The venae cordis ventrales are absent. This may be called the sinus-type or the collecting type and is encountered in this material in 53 hearts (33%) (Fig. 15). *Type 2.* Part of the coronary venous system opens directly into the right atrium (the venae cordis ventrales), but a considerable part of the dorsal wall of the right ventricle is also drained by the vena cordis parva. Type 2 may be regarded as the intermediate type. It is present in 45 hearts of this material (28%) (Fig. 12). *Type 3.* Only the coronary veins of the left ventricle open into the sinus coro-

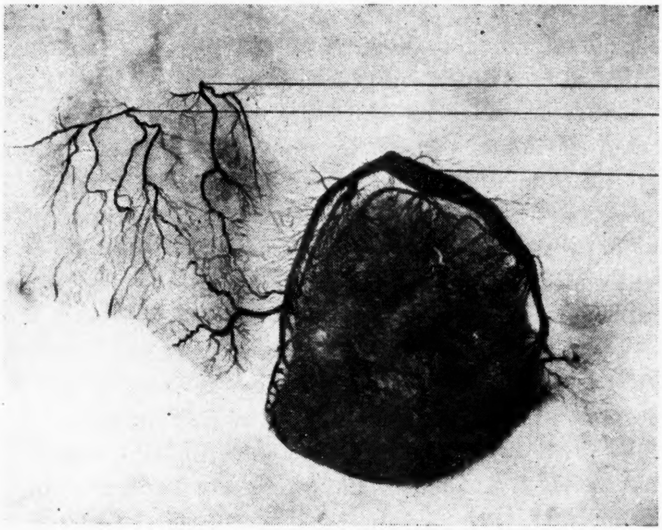


Fig. 11. The coronary veins of the left ventricle open into the sinus coronarius (b), and the veins of the ventral wall of the right ventricle open directly into the right atrium (a).

narius and the veins of the ventral wall of the right ventricle directly (Fig. 11) into the right atrium (the venae cordis ventrales). This type may be called the divided type. It is encountered in 62 hearts (39%).

The coronary venous system may also be divided according to its distribution in the various layers of the heart: 1) the superficial veins (subepicardial), and 2) the deep veins (intramural and subendocardial). This division is already applied by MECHANIK and GREGG.

Superficial Coronary Veins

The subepicardial part consists of all prominent venous trunks included in the *I.N.A.*, as well as their visible superficial branches. The size of the veins varies within the range of scarcely perceivable slender vessels and great venous trunks, but the general picture is best characterized by these great venous stems and their constant localization. The main role of the subepicardial veins appears to be to serve as outlets for the venous branches draining the cardiac muscle and to collect the venous blood of that muscle into the right atrium. The morphology of this system has already been described, and its veins are the most prominent in size.

Deep Tributaries The deep veins of the coronary venous system do not consist of independent coronary veins. These vessels, all of them, are tributaries of the superficial veins. The deep venous branches, consequently, are small in size, but lie closer to each other than the superficial ones. The main role of the deep tributaries seems to be to maintain the connection with the network of the capillaries, and their course largely follows that of the muscle fibres.

The network of venous branches emerging from the septum interventriculorum, the papillary muscles of the ventricles, and the coronary venous system of the trabeculae, consists of deep lying vessels exclusively. The coronary system of veins lying beneath the endocardium is very poorly developed, and in the present material scarcely always perceivable by the naked eye. The trabeculae of both ventricles always show in their muscle tissue branches of those coronary veins which are derived from either the septum interventriculorum, the apex, the posterior wall of the left ventricle, or the ventral wall of the right ventricle, according to the localization of the trabeculae. They form very variably a venous system of their own, as it were, between the septum and the venous network of the external surfaces of the heart. They are not referable to the venous system of the borderline zone exclusively, as they are also tributaries of either the venae dorsales ventriculi sinistri or the venae cordis ventrales, depending on the localization of the bases of the trabeculae. An effort to describe in the present work these branches in detail was met with insurmountable difficulties, owing to their great number, small size, fragility, and variableness. The author restricted himself to noting that they receive tributaries from all coronary veins included in the *I.N.A.*, and that the same trabecula may simultaneously receive venous branches from several coronary veins, mostly according to the size of the trabecula and the course of its muscle fibres, which are attached to the external cardiac wall and to the septum. Not infrequently the venous flow of a trabecula was directed both to the septum interventriculorum and to the external wall of the heart.

It was not possible to make a preparation, for the purpose of study, of the tributaries of those coronary veins which arise from the papillary muscles, because of their small size and great number. Hence it follows that the study of this distribution was mainly

carried out by radiographical methods. The numerous coronary venous branches draining the papillary muscles of the left ventricle seem to extend over nearly the whole length of the muscle, whereas the corresponding branches of the right ventricle appear less fully developed and less numerous. No true venous stem is seen in these muscles. It is only in the heart wall that the venous branches unite to form somewhat larger tributaries, which terminate, without exception, by opening very variably into a number of superficial veins. It is of interest to note that the venous branches of the papillary muscles in the present material are again seen to follow the course of the muscle fibres. In consequence their venous blood constantly flows to that superficial branch towards which the muscle fibres are directed and not, as could be presumed, to the nearest superficial branch. No detailed picture of the venous system of the papillary muscles could be obtained, morphologically, on the basis of this material.

Venae Cordis Minimae

(Venae Thebesii)

The absence of true venous trunks with prominent outlets and with openings at given points in the heart muscle, differentiates the venae cordis minimae system from the coronary venous system. In great numbers, but diffuse in arrangement, and small in size, the venae cordis minimae open into the various cavities of the heart.

Right Atrium

The venae cordis minimae draining the right atrium are very prominent — some of them as large as 2 mm in diameter. 4 to 10 orifices, serving as terminal openings for numerous venae cordis minimae, can be detected in the endocardium by the naked eye. These orifices (the foramina venarum minimarum) are always situated at constant points, frequently in radiate arrangement around the limbus fossae ovalis, between the terminal opening of the vena cava cranialis and the ostium atrioventriculorum (dextrum), in the mid-area of the wall of the right atrium. Those venae cordis minimae which open into the right atrium are distributed over its entire area and extend as far as the septum atriorum, but occasionally they reach the external dorsal wall

of the left atrium draining a considerable part of it, too. One or two venae cordis minimae, less than 1 mm in diameter, frequently open into a triangular area enclosed between the orifice of the sinus coronarius, the fossa ovalis, and the ostium atrioventriculorum (dextrum). A great number of these branches can very often be traced as far as the basal area of the septum interventriculorum. It is recorded by BOCHDALEK and UNGER that the venae cordis minimae may open into a sinus-like depression. This finding is also made in one case of the present material. In this case the orifice of the venae cordis minimae is completely covered by a valvular fold. One or two additional veins, small but perceptible, which may be interpreted as venae cordis minimae, open into the neighbourhood of the orifice of the vena cava cranialis and extend from the dorsal half of the groove lying between the conus arteriosus and the atria to the base of the conus arteriosus. This arrangement is not infrequently noted in post-partum subjects, but occasionally also in adults. Venae cordis minimae occur in the external dorsal surface of the right atrium, in the neighbourhood of the opening of the vena cava caudalis, but in this region they are small in size. The venae cordis minimae of the right auricle are scarcely perceptible. The results of this study are consistent with the findings yielded by earlier investigations (e.g. BOCHDALEK, LANNELONQUE, LANGER, UNGER, HALONEN & TOSSAVAINEN).

Left Atrium The prominent venae cordis minimae system of the left atrium is invariably situated in the region adjacent to the right atrium and in the neighbourhood of the septum atriorum (e.g. BOCHDALEK). In UNGER's findings these veins are absent on the ventral surface of the left atrium, but prominent on the dorsal surface. HALONEN & TOSSAVAINEN note that they also occur on the ventral surface. The extent of the venae cordis minimae system of the left atrium varies according to the stage of development of the vena obliqua atrii sinistri and the rami atrii sinistri (e. g. BOCHDALEK). The foramina of the venae cordis minimae are not always perceptible in the endocardium. When macroscopically, they are found to occur in the neighbourhood of the septum atriorum. Very slender venae cordis minimae are also seen on the ridge of the left auricle, but they are few in number. UNGER points out, »Auch bei Injectionen in den Coronarsinus zur Darstellung der Coronarvenen des linken Vorhofs, habe ich ausser in dem

angeführten Bereich keinen Austritt von Injectionsmasse beobachten können.» If the injection material is liquid enough, the venae cordis minimae of the left atrium are definable in the material examined, and moreover, part of the venae cordis minimae of the right atrium can be defined by injecting the material through the sinus coronarius (Fig. 15 and 17).

Right Ventricle

The venae cordis minimae system of the right ventricle can be displayed by injecting the material from either the sinus coronarius or the right ventricle. Their abundant occurrence in the present material is in conformity with the findings of LANGER, UNGER, and HALONEN & TOSSAVAINEN, according to which they are numerous and occur most abundantly in given areas. In the region of the conus arteriosus the venae cordis minimae can be defined only with difficulty. According to LANGER, they occur mainly there, while UNGER, as well as HALONEN & TOSSAVAINEN, do not find them to be numerous. In the trabeculae, on the other hand, and in the apical region of the heart they find a great abundance of venae cordis minimae. In uninjected hearts in this material they are to be detected only with difficulty by the naked eye. According to UNGER and the literature on the venae cordis minimae published after him, the number of these veins is very significant in the region of the right ventricle.

The findings from the present material on the distribution and number of the venae cordis minimae of the inner surface of the right ventricle are compatible with earlier research on human hearts (e.g. LANGER, WEARN, UNGER, HALONEN & TOSSAVAINEN, WINDT). The observations made may, consequently, be summarized in the following points:

1). The venae cordis minimae are situated in the inner surface of the right ventricle, their size and number being directly proportional to the area of their distribution.

2). On macroscopical estimation, their number appears fairly small, but many areas in the present material, taken at random and subjected to histological study, show a great abundance of these veins.

3). In the smooth walls of the right ventricle their number is small, and on macroscopical inspection, they seem to be absent.

4). An abundant occurrence of the venae cordis minimae is seen by the naked eye in the trabeculae, particularly in their

posterior parts and in the hollows between them, but they are not infrequently visible only after removal of the superficial trabeculae. The terminal openings often occur at the roots of the trabeculae.

5). The venae cordis minimae system of the m. papillaris ventralis et dorsalis (RV), lying beneath the endocardium, entirely covers this muscle and is partly inserted into the muscle tissue, particularly in its proximal part. The direction of the blood flow is often towards the base of the papillary muscle.

6). The apical region of the heart is plentifully supplied with venae cordis minimae. Histological examination of this material shows that they penetrate deep into the heart muscle, mostly vertically, immediately from the orifice.

7) Very slender venae cordis minimae, emptying into the right ventricle, are seen in the proximal half of the septum.

8) The venae cordis minimae which emerge from the right ventricle are considerably smaller in size than those of the right atrium, their largest terminal openings being, as a rule, less than 0.5 mm in width.

9) Only the venae cordis minimae lying beneath the endocardium and those anastomosing with them, both of which open by separate foramina (at the base of the trabeculae) and are inserted straight into the heart muscle, are, consequently, well-defined in the present material.

Left Ventricle

In the material examined the venae cordis minimae system of the left ventricle is most poorly developed. Langer, Unger, and Halonen & Tossavainen consider insignificant its share in transmitting the venous blood into the left ventricle. In the author's material the findings on the venae cordis minimae of the left ventricle do not differ in any noticeable degree from those of other investigators. They may be summarized as follows:

1) They are few in number and are always situated in given areas of the ventricle. They are also very superficial in position.

2) Very likely they are not always perceptible macroscopically in the smooth-walled part of the ventricle.

3) They were most numerous in the trabelucae, the papillary muscles, and the apical region.

4) In the author's material the trabeculae show again the presence of venae cordis minimae running subendocardially through-

out their course. These venae cordis minimae, again, anastomose with those which open by separate foramina and are inserted straight into the cardiac muscle substance.

In the material examined the venae cordis minimae of the marginal regions of the right atrium are found to fill after perfusion with the injection dye via the sinus coronarius (Fig. 17) and occasionally also via the right coronary artery, though only partially and indistinctly. The main part can be displayed by perfusing with the injection material the right atrial cavity. The venae cordis minimae of the left atrium are most well-marked, if injected from the sinus coronarius. In the two ventricles the venae cordis minimae can be displayed by perfusing with dye the coronary veins, but the result will be more successful, if the ventricular cavities are perfused (e.g. WEARN). According to UNGER, they are made visible by injection from either the ventricles or from the coronary veins, whereas WINDT emphasizes that the venae cordis minimae of the left ventricle can be displayed by injecting the coronary arteries, and those of the right ventricle by injecting the coronary veins.

Density Relations of Coronary Veins and Venae Cordis Minimae System

The literature surveyed by the author does not give any details on the density and size relations of the systems of the coronary veins and the venae cordis minimae. Those investigators who have studied the venae cordis minimae (e.g. LANGER, UNGER, HALONEN & TOSSAVAINEN, and WINDT) only demonstrate, in which regions of the heart the occurrence of these veins is most prominent, but do not go into a detailed study of the subepicardial venous system. In addition to their research work, physiological experiments, such as those described, have been carried out in order to make clear the role of the venae cordis minimae, but again without going into the details of the coronary veins.

Physiological experiments have led to the conclusion that a large proportion of the venous flow of the left ventricle is drained into the sinus coronarius (e.g. KATZ, JOCHIM, et al., MOE & VISSCHER), and that the blood discharged by the left coronary artery

is also emptied, in the main, into the sinus coronarius (e.g. EVANS & STARLING 1913, ANREP, BLALOCK, et al. 1929, GREGG, SHIPLEY, et al., GREGG & SHIPLEY). In the region of the right ventricle the ratio of the flow of the coronary veins to that of the venae cordis minimae is more difficult to determine. There are investigators, who ascribe the venae cordis minimae system of the right ventricle a prominent role as drainer of the heart muscle, while others emphasize more the significance of the venae cordis ventrales (e.g. GREGG & SHIPLEY).

In the concurrent study of these two systems, however, great divergences in their ratio have been shown in the various parts of the hearts in this material. These divergences always seem to serve some specific purpose.

Right Atrium

In the material examined the purpose of the divergences of the ratio of the coronary veins and the venae cordis minimae is most manifest in the region of the right atrium. The coronary veins are absent practically throughout this region, it being drained almost exclusively by the venae cordis minimae. It is noted by CRUVEILHIER, HENLE, LANNELONQUE, PIQUAND, CUNNINGHAM, and UNGER that small coronary veins, originating in the neighbourhood of the sulcus coronarius in the region of the right ventricle, open into the vena cordis parva. The same observation is made by the author in the present material, although he, in accordance with UNGER, also finds that vessels of the coronary venous system distributed over the external dorsal surface of the right ventricle extend only as far as the surroundings of the orifice of the vena çava caudalis, in which region the number and size of the venae cordis minimae are found to be insignificant. Another region occupied by veins of the coronary system is found on the surface of the right auricle, in the neighbourhood of the groove which lies between the right auricle and the conus arteriosus. Whenever these coronary veins are absent or poorly developed, the venae cordis minimae lying towards the vena cava cranialis appear to be well-defined in the present material. The coronary venous system of the right atrium is scarce, and the main drainers of the right atrium are the venae cordis minimae.

Left Atrium

The density relations of the various systems are not so distinct in the region of the left atrium as in the right. In the former, however, the branches of the coronary venous system are found

to be more numerous (the vena obliqua atrii sinistri and the rami atrii sinistri). Cruveilhier, Quain, and Cunninghamn describe small branches occurring in the wall of the left atrium and opening into the transverse portion of the vena cordis magna or into the sinus coronarius. According to the students of the venae cordis minimae system, on the other hand, the venae cordis minimae of the left atrium are less numerous than those of the right. Unger records that they are absent in the region of the vena obliqua atrii sinistri, the most prominent of the venae cordis minimae of the left atrium being found in its dorsal wall. In the present material there is an abundance of venae cordis minimae in the region of the septum atriorum, which seems to be occupied almost exclusively by them.

The radicles of the vena obliqua atrii sinistri usually bound the most prominent venae cordis minimae of the left atrium. They drain the dorsal wall of the left atrium, i.e. the area lying between the vena obliqua atri sinistri and the septum atriorum, and open not infrequently into the right atrium.

Right Ventricle

In the author's material the coronary system of veins is of fairly slender structure in the subendocardial part of the right ventricle, whereas the venae cordis minimae seem to predominate in the major part of this region. The coronary venous system forms areas of bifurcation, in which the venous flow divides to proceed in two directions. Such an area is found proximally to the sulcus interventricularis ventralis, between the radicles of the rami ventriculi dextri, part of which open into the venae cordis ventrales or the vena cordis parva and another part into the vena cordis magna or the vena interventricularis dorsalis cordis. An additional area of bifurcation occurs in the sulcus interventricularis ventralis cordis itself, between the vena cordis magna and the vena interventricularis dorsalis cordis. In the ventral wall of the right ventricle there is, consequently, a fairly extensive area, from which the venous blood proceeds in three directions: one part of it towards the great curvature of the vena cordis magna, another part, proximally, towards the sulcus coronarius, and a third part towards the apex of the heart. This distribution extends through the ventral wall of the right ventricle as far as the trabelucae. The interspace between the branches of the coronary venous system of the marginal zone also presents a bifurcation area, which

is situated in the region of the right ventricle, or more exactly, in the septum interventriculorum and its trabelucae. The entire area of the right ventricle seems to be encircled by a continuous zone of bifurcation, and in this zone the trabeculae are partly placed There would, moreover, seem to be ground to emphasize the fact, that the coronary venous system of the right ventricle is markedly less well developed than that of the left ventricle (e.g. MECHANIK).

In the present material the venae cordis minimae system is localized in the apical region and the trabeculae of the right ventricle, which fact has been noted before. The proximal part of the septum interventriculorum, adjacent to the right atrium, receives venae cordis minimae from the region of this atrium. In the cases examined it appars evident that, where the coronary venous system is not fully developed, it is replaced by the venae cordis minimae system. This replacement has been observed in the right ventricle as well, where the coronary venous system is far less prominent than in the left ventricle. It is particularly manifest in the m. papillaris ventralis et dorsalis (RV). This muscle is found, e.g. by UNGER, to be drained by the venae cordis minimae exclusively, but in the author's material it is constantly seen to be reached by branches of coronary veins as well.

Left Ventricle

The coronary system of veins is most prominent in the region of the left ventricle, the venae cordis minimae system, on the contrary, is weakest in this region. Areas of bifurcation may be defined distinctly only within the range of the coronary veins of the marginal zone and in the apical region of the left ventricle. The venae cordis minimae system is, further, perceptible in the trabelucae of the left ventricle, in the apical region, and the papillary muscles. In these regions, however, the coronary venous tributaries are invariably prominent, draining the most part of them, while the venae cordis minimae do not penetrate very deep into the intramural substance.

The general impression obtained of these density relations appears to be that the venae cordis minimae are prominent in the region of the right atrium and the adjacent areas of the heart, and, moreover, in the so-called bifurcation areas. Besides, their frequency of occurrence always varies according to the supply of coronary veins.

Anastomoses

Anastomoses between Coronary Veins

In the author's material, as in the cases examined by MECHANIK, the anastomoses between the coronary veins can be divided into two types: 1) the terminal anastomoses, and 2) the lateral anastomoses.

Terminal Anastomoses

The terminal anastomoses always occur at constant points on the external surface of the heart. The main venous stems, i.e. the vena cordis magna, the vena interventricularis dorsalis cordis, the ramus dorsalis ventriculi 2, and the rami ventriculi dextri 1 (the vena cordis parva or the venae cordis ventrales), form in this manner a strong network of venous trunks, which occupies the sulcus interventricularis dorsalis cordis and ventralis cordis as well as the margo acutus sinistri and dextri. It may occasionally be obscured by the systems of the venae dorsales ventriculi sinistri and the venae cordis ventrales, but only by them. The ramus dorsalis ventriculi 2 are frequently absent, or the system of the venae dorsales ventriculi sinistri is divided into multiple stems, which in their whole extent constitute the frame of the network of the terminal anastomoses. The occurrences of these anastomoses are described by MECHANIK as follows, »Zu solchen Anastomosen gehört die beständige Anastomose zwischen der Vena cordis magna und Vena cordis media, Vena cordis media und Vena ventriculi sinistri posterior, wobei die letzte zum Unterschied von der ersten häufig eine Anastomose im Verlauf der Gefässe darstellt . . .»

In this material, moreover, the anastomoses of the vena cordis parva with the rami ventriculi dextri 1 (the venae cordis ventrales) may be included to the terminal anastomoses. Where the vena cordis parva is poorly developed, it anastomoses with the rami ventriculi dextri 1 (Fig. 12), either in the sulcus coronarius or in its surroundings. The secondary orifices (»Nebenmündungen») of the vena cordis parva, observed by MOCHIZUKI, are also present in this material, but very rare in occurrence, and even when present, they are not readily differentiated from the anastomosis described.

Where the vena cordis parva is fully developed, the entire

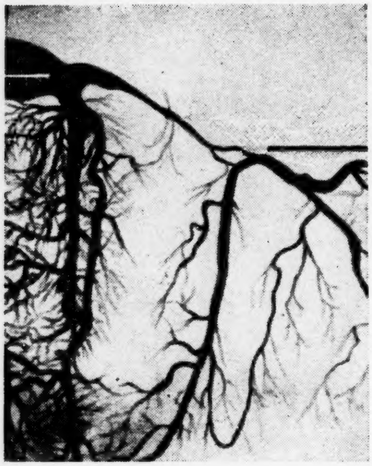


Fig. 12. The terminal anastomosis (a) between the vena cordis parva (c) and the venae cordis ventrales (b).

network of the terminal anastomoses opens into the sinus coronarius. Where the venae cordis ventrales are present, the network empties on the right side directly into the right atrium. But where the vena cordis ventrales and the vena cordis parva are coexistent, the right side of the main network is connected both to the sinus coronarius and the right atrium.

Lateral Anastomoses

As a general impression obtained from the material examined, it may be stated that all wider branches throughout the course of the venous trunk anastomose freely with one another. The heart surface, consequently, appears to be occupied by a loose network of coronary veins. Each of the various venous trunks in turn was ligated experimentally before starting the injection. In spite of this, filling the entire coronary venous network with the injection material was not attended with any difficulties worth mentioning. The surface of the left ventricle, in particular, presents a very close network of anastomoses, single anastomoses being anything but easy to define because of their great number. An anastomotic network, although not so well-marked, is also present on the surface of the right ventricle. It is again less prominent between the rami ventriculi dextri of the vena cordis magna and the vena cordis parva or the rami ventriculi dextri of the venae cordis ventrales, whereas the rami ventriculi dextri of the vena interventricularis dorsalis cordis, and those of the vena cordis parva, or of the venae cordis ventrales, anastomose very freely and markedly. MECHANIK calls attention to the abundant occurrence of these anastomoses.

In the region of the conus arteriosus the coronary venous network is always well-defined, but as a rule, it is more difficult to define true cords of veins (Fig. 16).

The material examined shows, in addition, the presence of a

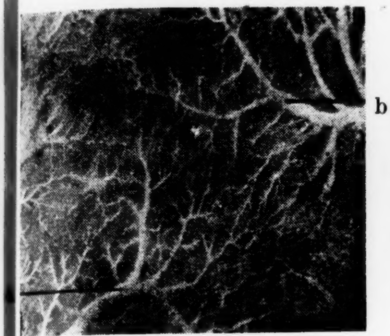


Fig. 13. Small lateral anastomoses on the surface of the left ventricle between the vena cordis magna (a) and the venae dorsales ventriculi sinistri (b).

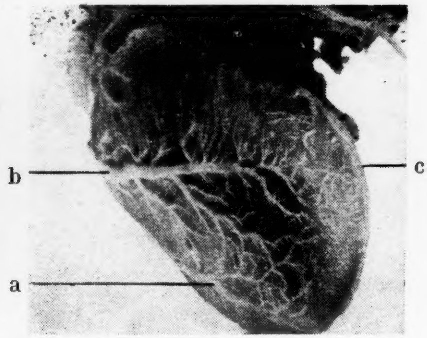


Fig. 14. Lateral anastomoses between the vena interventricularis dorsalis cordis (a), the vena cordis parva (b), and the vena cordis magna (c).

very close anastomotic network in the subepicardial substance. Each of the tributaries of the main venous trunks receives scarcely visible radicles, which stretch over the whole area of the left ventricle anastomosing with one another. This fine, close network only very occasionally extends as far as beyond the coronary veins.

Anastomoses also occur in the intramural network. They particularly occupy areas of bifurcation, but occur in the septum interventriculorum as well. These anastomoses are with the greatest difficulty perceptible macroscopically.

The intramural system is dense, but the larger anastomoses do not appear so dense as in the subepicardial part. They would seem to be required only to direct the blood flow to follow, in the main, the course of the muscle fibres. Only in the subepicardial part do the marked changes of direction take place.

Arterio-Venous Anastomoses

The anastomoses between the coronary veins and arteries are not easy to define (e.g. Kretz, Langer, Windt). Injections with glass beads have been carried out lately (e.g. Prinzmetal, Simkin, et al.). This method has also been applied in the present work.

Diameters of the arterio-venous anastomoses, yielded by the present research material, are presented below in tabular form. Their maximal sizes range from 60 to 210 μ, while the figures obtained by Printzmetal, Simkin, et al. vary from 60 to 210 μ.

Table IX: Arterio-Venous Anastomoses. Diameter in Various Age Groups

Age	Maximum in μ:s	Age	Maximum in μ:s
P P	60	21 yrs	140
»	150	—»—	180
»	70	23 yrs	140
»	130	—»—	170
»	100	24 yrs	210
»	140	33 »	140
»	100	—»—	100
»	110	40 yrs	90
»	90	44 »	90
»	90	51 »	140
»	170	57 »	210
»	100	63 »	110
»		66 »	80
Mean of maximum values	110 ± 10		138 ± 12

Extra-Cardial Anastomoses

The study of the extra-cardial anastomoses is confined to the venous anastomoses leaving the heart. In the regions which cover the sites of attachment of the great blood-vessels, the radicles of the coronary veins form a close continuous venous network, which follows the course of the great vessels entering and leaving the heart. The venous network extends along these vessels (the aorta, the arteria pulmonalis, and the vena cava cranialis) and receives a number of slender veins, which open into the vena cava cranialis in the neighbourhood of the heart, either as separate stems or in company with small nameless veins emerging from the region of the mediastinum. Their openings may be situated at various levels: 1) One or several small veins, emerging from the grooves between the conus arteriosus and the atria, and connected with the network of the conus arteriosus, open at the entrance of the vena cava cranialis. 2) The vena cava cranialis is frequently entered, dorsally to the base of the great arteries, by two or three veins, about 1 mm in width, arising from the site of attachment of the pericardial sac in the region of the arcus. These veins anastomose with the rami coni arteriosi and the rami atrii sinistri of the vena cordis magna, as do those of the previous group, which simultaneously anastomose with the corresponding branches of

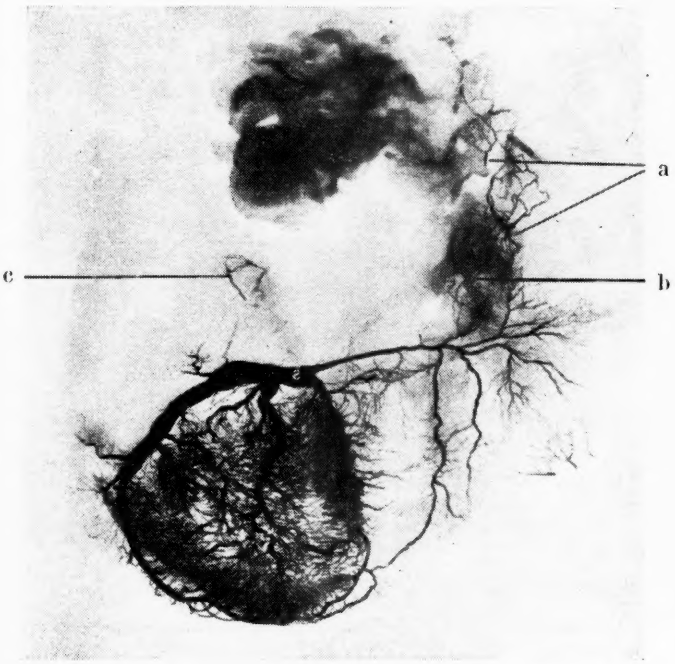


Fig. 15. The general system of the coronary veins empties into the sinus coronarius. The small nameless veins of the mediastinum (a) anastomose (b) with the branches of the vena cordis parva. The venae cordis minimae (c) anastomose with the rami atri sinistri.

the vena cordis parva or of the venae cordis ventrales. 3) At the point of bifurcation of the vena cava cranialis, in addition, there is seen the terminal opening of a slender network of veins issuing from the basal stems of the great arteries and being situated in the ventral part of these basal stems and in the mediastinum.

A very slender and very poorly filled vein, anastomosing with the radicles of the vena obliqua atrii sinistri and the rami atrii sinistri, is occasionally encountered in the region of the pulmonary hila (Fig. 17).

The hearts have been detached from the thorax by HAMPERL's dissection technique, the vena cava caudalis being cut off at the level of its terminal opening. Consequently, the anastomoses directed towards the vena cava caudalis cannot be examined in the

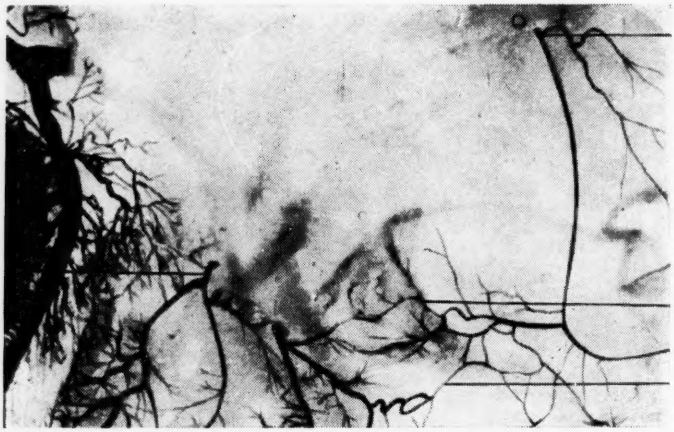


Fig. 16. The rami coni arteriosi (c) of the venae cordis ventrales (a) anastomose with the small veins of the mediastinum which open into the vena cava cranialis(b).

present material, although the vena cordis parva is seen to receive slender tributaries from the surrounding of the vena cava caudalis.

Anastomoses between Venae Cordis Minimae

The material examined by the author shows that the venae cordis minimae may anastomose with one another anywhere on the inner surface of the heart. The most prominent anastomoses, however, occur within the areas of the two atria. The density of the anastomoses is directly proportional to the size and number of the venae cordis minimae, in conformity with earlier investigations (e.g. UNGER, WINDT). In the regions of the two ventricles the author's material occasionally shows the occurrence of two various types of venae cordis minimae in the same trabecula: those mainly subendocardial and those penetrating deep into the heart muscle. The two types may anastomose with one another.

Fig. 17. The rami atrii sinistri anastomose with the (a) venae cordis minimae of the left atrium and with the vasa vasorum of the venae pulmonales (b).

Anastomoses between Venae Cordis Minimae and Coronary Arteries and Veins

The size of the anastomoses connecting the coronary arteries and veins to the venae cordis minimae is determined by perfusing the coronary vessels with an injection material mixed with glass beads.

Table X: Diameters of Anastomoses Connecting Coronary Arteries and Veins of Left Ventricle to Venae Cordis Minimae

Age	Maximum in μ:s	Age	Maximum in μ:s
P.P.	100	21 yrs	170
»	80	—»—	180
»	100	23 yrs	110
		—»—	180
»	170	24 yrs	200
»	110	33 »	280
»	70	33 »	80
»	50	40 »	60
»	180	44 »	100
»	90	51 »	180
»	170	57 »	170
»	170	63 »	90
»	110	66 »	100
Mean of maximum values	117 ± 13		145 ± 17

Table XI: Diameters of Anastomoses Connecting Coronary Arteries and Veins of Right Ventricle to Venae Cordis Minimae

Age	Maximum in μ:s	Age	Maximum in μ:s
P.P.	80	21 yrs	200
»	160	—»—	190
»	90	23 yrs	180
		—»—	180
»	150	24 yrs	240
»	110	33 »	150
»	170	—»—	100
»	60	40 yrs	100
»	40	44 »	120
»	70	51 »	100
»	180	57 »	280
»	140	63 »	100
»	70	66 »	150
Mean of maximum values	110 ± 14		160 ± 18

The maximum sizes of the glass beads obtained from the right ventricles of the material examined range from 40 μ to 280 μ, those from the left ventricles 50 μ to 280 μ, being consistent with the figures obtained by PRINZMETAL, SIMKIN, et al. (varying from 70 μ to 280 μ).

In the two atria the anastomoses lying between the vena obliqua atrii sinistri and the venae cordis minimae of the two atria and connecting the coronary veins to the venae cordis minimae are definable by radiography. Only very occasionally, glass beads are discharged in experiments on the atria, the maximum values, however, ranging only from 30 μ to 130 μ.

Comparison

The accompanying table ((Table XII) gives the means of the maximum values for the glass beads discharged from all hearts examined, as well as their standard errors, with a view to making a comparison between the various groups (p.p. and a.)

Table XII: Comparison of Means of Maximum Values for Groups P.P. and A. on the Basis of their Standard Errors

Source of Glass Beads	P P	A
Sinus coronarius	110 ± 10	138 ± 12
Right atrium	77 ± 10	79 ± 6
Right ventricle	110 ± 14	160 ± 18
Left atrium	65 ± 6	91 ± 13
Left ventricle	117 ± 13	145 ± 17
Coronary arteries	92 ± 10	124 ± 10
	(m) 95 ± 4,4	123 ± 5,4
	Difference (28) > 3.3 x 7.0[1]	p < 0.1 %

A presentation of the frequency of occurrence of the various sizes of the glass beads discharged in the glass bead experiments is given with a view to comparing again groups p.p. and a. The grouping applied in the comparison is reproduced in the following tables.

[1] $7.0 = \sqrt{4.4^2 + 5.4^2}$

Table XIII: Size and Number of Total of Glass Beads Discharged from Sinus Coronarius in Cases Examined

Size of Glass Beads	P P		A	
	No	Relative No	No	Relative No
30 μ	632	0.547	595	0.428
40 μ	382	0.330	439	0.315
50 μ	74	0.064	131	0.094
60 μ	25	0.022	60	0.043
70 μ	22	0.019	38	0.027
80 μ	4	0.003	48	0.034
90 μ	4	0.003	21	0.015
100 μ	8	0.007	24	0.017
110 μ and larger ..	6	0.005	35	0.027
	1157	1.000	1391	1.000

$\chi^2 = 98.41 \quad p < 0.1\,\%$ (8 degrees of freedom)

Table XIV: Size and Number of Total of Glass Beads Discharged from Right Ventricle in Cases Examined

Size of Glass Beads	P P		A	
	No	Relative No	No	Relative No
30 μ	610	0.517	668	0.487
40 μ	375	0.317	359	0.262
50 μ	73	0.062	157	0.115
60 — 70 μ	75	0.063	90	0.066
80 — 100 μ	36	0.030	63	0·046
110 μ and larger ..	13	0.011	33	0.024
	1182	1.000	1370	1.000

$\chi^2 = 37.80 \quad p < 0.1\,\%$ (5 degrees of freedom)

Table XV: Size and Number of Total of Glass Beads Discharged from Left Ventricle of Cases Examined

Size of Glass Beads	P P		A	
	No	Relative No	No	Relative No
30 μ	516	0.457	693	0.540
40 μ	416	0.369	304	0.237
50 μ	96	0.085	128	0.100
60 — 70 μ	56	0.050	73	0.057
80 — 100 μ	23	0.020	51	0.040
110 μ and larger ..	22	0.019	34	0.026
	1129	1.000	1283	1.000

$\chi^2 = 54.60 \quad p < 0.1\,\%$ (5 degrees of freedom)

Summary

1) Various research methods have been applied in the investigations directed to the venous systems of the human heart and its arterio-venous anastomoses.

2) The selection of the material was influenced by the consideration of dividing it into fairly equal groups (p.p., a.; ♂ and ♀) to secure acomparison of the material.

3) The question of confusing nomenclature was dealt with, the names of the venae coronariae being, as far as possible, standardized in conformity with the *I.N.A.*

4) The investigations on the sinus coronarius were mainly carried out in the a. group. The earlier investigators showed disagreement in their opinions, neither could the results obtained from the present material always be found to be compatible with those of other investigations.

5) Comparison of differences between the various coronary venous systems and individual venous trunks in the different groups was carried out. Slight differences between the four groups were noted.

6) Comparative study with a view to defining anthropological differences were carried out chiefly in Japanese and Finnish hearts. It occasionally revealed appreciable differences.

7) Piquand's and Mechanik's reduction theory could not be confuted on the basis of this material.

8) The investigations on the venae cordis minimae did not bring to light any new details of significance. Slight variations in the opinions of earlier investigations were noted.

9) The arrangement of the anastomoses between the coronary veins, arteries, and venae cordis minimae was found to be well-developed in the human heart.

10) The variations in the density relations of the coronary veins and the venae cordis minimae were considered to serve a specific purpose, i.e. to compensate for any deficiencies occurring in either of the two systems.

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